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VOLUME IV

(April, 1975 - March, 1976)

by

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ABSTRACT

This report discusses the results from the third year of field runoff studies with fall, winter and spring applications of fluid sewage sludge on land cropped with grain corn. Runoff of water, soil, nutrients and metals were measured. The report also covers field rate and source studies with three sludges resulting from treatment of sewage with calcium hydroxide, ferric chloride, and aluminum sulphate for phosphorus removal. One experiment involves surface sludge applications on a loam soil on which bromegrass is grown, and three trials involve corn on a loam, a sandy loam and a clay loam soil. In one greenhouse experiment, nine fluid sewage sludges, selected for their high metal content, were applied to a soil previously adjusted to two pH levels. Five crops of ryegrass were grown with sludges added to the soils before each crop. Crops growth, and nutrient and metal uptake were studied along with micropedological studies of the soils. The sludges and field-grown crops were monitored for pathogenic organisms. Field experiments and laboratory studies were used to estimate the nitrogen availability from sludge and the rates of volatilization of nitrogen from surface applied sludge in the field. A greenhouse experiment was also run on a group of soils varying in metal content. The soils were extracted with various chemicals in an effort to find suitable extractants for plant available cadmium, copper, nickel, lead and zinc.

Total runoff in 1975 was similar to 1973 and 1974, as were nitrogen, phosphorus and metal losses. Metal losses were small and mostly associated with summer losses of soil solids. Runoff from a 6% slope was similar to that from a 2% slope in winter but greater in summer. Sludge application had no effect on total runoff volume.

In the field rate and source studies the bromegrass had slightly higher yield with sludge than with ammonium nitrate. At low rates of application the calcium sludge tended to produce lower yields and higher yields at higher rates of application than the other sludges, a trend which was apparent in 1974.

The sludges markedly increased sodium bicarbone-extractable, "plant available" soil phosphorus, with the calcium sludge being much

more effective than the other sludges. Phosphorus concentrations in the crops were high and unaffected by treatment.

Cadmium content of both grass and corn stover was increased by sludge application, the effect being greatest with the sludge supplying the most cadmium. Nickel, chromium and copper were increased in some plant tissues at some sites, but the effects were not consistent. Zinc concentration increased in bromegrass, corn grain, and at one site in corn stover. Molybdenum in plant tissue appeared to increase with sludge application.

In the greenhouse study, increased rates of sludge applied at one time increased the concentrations of metals in ryegrass. Repeated cycles of sludge application and cropping did not increase metal concentrations in the ryegrass from one crop to the next (up to the fifth crop) at any of the rates studied. One application of sludge resulted in nickel concentrations in the first three crops of ryegrass that were as high as in treatments receiving three applications of the same amount of sludge. Cadmium, copper and zinc showed slightly reduced concentrations in later crops of ryegrass where sludge was applied only once.

As in previous years, NH_4^+-N applied in sludge was rapidly transformed to NO_3^- in the soil in the field. Leaching of NO_3^- was apparently greater during the fall in the sandy loam soil than in the other finer textured soils. There was some evidence of release of NO_3^- from sludge applied to the clay loam in the previous two years. Sludge applications had little influence on NH_4^+ and pH levels in the soils, with the exception of calcium sludge which significantly increased pH. The concentration of NO_3^--N in the soil solution generally exceeded the accepted level of 10 μg NO_3^--N/ml, particularly where larger quantities of sludge were applied.

Chemical treatment of sludges had no apparent effect on NO_3^- production from sludges mixed in soil. However, sludge from Point Edward resulted in relatively slow NO_3^- production, suggesting an inhibitory substance present in the sludge. Approximately two-thirds of the organic nitrogen fraction of sludges was mineralized during a 49-day incubation period in the laboratory.

Salmonella species were detected during the 1975 season in sludges (11 of 15 samples) and corn (4 of 24 plot samples). *Salmonella* species were not detected in the runoff waters (132 samples) or in the grass samples (36 plot samples).

RÉSUMÉ

Le présent rapport traite des résultats de la troisième année d'étude sur le ruissellement des boues fluides épandues l'automne, l'hiver et le printemps sur des champs destinés à la culture du maïs. Le déplacement de l'eau, du sol, des matières nutritives et des métaux a été mesuré. Il y est aussi question des doses d'épandage et de l'origine de trois types de boues provenant de la déphosphatation des eaux usées avec de l'hydroxyde de calcium, du chlorure ferrique et du sulfate d'aluminium. Dans une des expériences, on a épandu les boues sur des terres grasses cultivées en brome et, dans trois autres, on a cultivé du maïs sur des terres grasses ordinaires, sur des terres grasses sablonneuses et sur des terres grasses argileuses. Dans une expérience en serres, neuf types de boues fluides, choisies pour leur haute teneur en métal, ont été épandues sur un sol préalablement ajusté à deux pH différents. On a effectué cinq récoltes de faux seigle en épandant des boues entre chaque période de culture. Parallèlement à des études micropédologiques, on a étudié la croissance végétale et l'absorption des matières nutritives et des métaux. On a aussi contrôlé les organismes pathogènes dans les boues et dans les produits récoltés dans les champs. Des expériences sur le terrain et en laboratoire ont permis d'évaluer la quantité d'ozote que peuvent rendre les boues et sa vitesse de volatilisation lorsque l'application se fait à la surface du sol. On a aussi affectué une expérience en serres sur des sols caractérisés par des teneurs variables en métaux. Ces sols ont été soumis à différents produits chimiques pour tenter de découvrir des agents d'extraction du cadmium, du cuivre, du nickel, du plomb et du zinc assimilables par les plantes.

En 1975, le ruissellement, ainsi que les perte d'azote, de phosphore et de métaux, ont été semblables à ceux de 1973 et de 1974. Les pertes métalliques étaient minimes et découlaient surtout des pertes en matières solides que subit le sol en été. En hiver, le ruissellement d'une pente de 6 p. 100 était semblable à celui d'une pente de 2 p. 100, mais il y était plus important en été. Le épandages n'ont pas affecté le volume total du ruissellement.

Les études des doses épandues et de la provenance des boues ont démontré que le rendement des cultures de brome était légèrement plus élevé qu'avec le nitrate d'ammonium. À des doses respectivement faibles et élevées les boues de calcium tendent à produire un rendement plus faible et plus élevé que les autres boues. Cette tendance avait déjà remarquée en 1974.

Les boues ont accru de façon marquée la proportion de phosphore du sol assimilable par les plantes et extractible par le bicarbonate de soude. Les boues de calcium se sont montrées beaucoup plus efficaces sous cet aspect. Dans les plantes récoltées, les concentrations de phosphore étaient élevées et n'étaient pas modifiées par le traitement.

Les épandages de boues ont augmenté la teneur en cadmium tant de l'herbe que des tiges de maïs, augmentation d'autant plus importante que la concentration en cadmium était plus élevée. La teneur en nickel, en chrome et en cuivre a augmenté dans certains tissus végétaux et à certains endroits, mais non de façon soutenue. La teneur en zinc s'est accrue dans le brome, les grains de maïs et, à un endroit, dans les tiges de maïs. L'application des boues a semblé augmenter le teneur en molybdène des tissus végétaux.

En serre, l'augmentation de la dose épandue en une fois a augmenté la teneur en métaux du faux seigle. Après des applications et des récoltes répétées, cette teneur n'a pas augmenté d'une récolte à l'autre (jusqu'à la cinquième) et ce, à aucune des doses étudiées. Une seule application des boues a donné, dans les trois premières récoltes de faux seigle, la même concentration de nickel que trois épandages. Les teneurs en cadmium, en cuivre et en zinc ont légèrement baissé dans les récoltes subséquentes de faux seigle où l'épandage ne s'est fait qu'une seule fois.

Comme dans les années précédentes, l'azote ammoniacal des boues s'est rapidement transformé en NO_3^- dans le sol. Le lessivage du NO_3^- à semblé plus important en automne, dans les terres grasses sablonneuses, que dans les autres types de sol à grains plus fins. Il a semblé y avoir dégagement de NO_3^- des boues appliquées sur les terres grasses argileuses au cours des deux années antérieures. L'épandage n'a eu que peu d'effets sur la concentration de NH_4^- et sur le pH des sols, à l'exception des boues de calcium qui ont augmenté le pH de façon significative. Les concentrations d'azote nitrique dans les solutions de sol dépassaient généralement le niveau limite de 10 µg/ml, surtout lorsqu'on avait appliqué de grandes quantités de boues.

Le traitement chimique des boues n'a eu que peu d'effets visibles sur la production de NO_3^- à la suite de leur incorporation au sol. Toutefois, les boues provenant de Point Edward n'ont donné qu'un faible dégagement de NO_3^-, ce qui pourrait indiquer la présence d'une substance inhibitrice. Environ les deux tiers de la fraction d'azote organique des boues se sont minéralisés pendant les 49 jours qu'a duré l'incubation en laboratoire.

Pendant la saison de 1975, on a détecté des Salmonella dans les boues (11 des 15 échantillons) et dans le maïs (4 des 24 parcelles de culture). On n'en a pas décelé dans les eaux de ruissellement (132 échantillons), ni dans les échantillons d'herbe (36 parcelles de culture).

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1. INTRODUCTION

This volume covers work done by the Departments of Land Resource Science and Microbiology at the University of Guelph on land disposal of sewage sludge. The work was financed by Fisheries and Environment Canada and the Ontario Ministry of the Environment under project 72-5-17 contracted by the Federal Department of Supply and Services, and covers the period from April 1, 1975 to March 31, 1976. Previous work under this project has been published as "Land Disposal of Sewage Sludge", Research Reports No. 16, 24 and 35 (designated Volumes I, II and III, respectively), Research Program for the Abatement of Municipal Pollution under provisions of the Canada-Ontario Agreement on Great Lakes Water Quality.

The research program proceeded on schedule during 1975/76. April weather did not permit as early a start on sludge hauling and spreading as had been hoped. However, May was warmer than usual and was followed at Elora by an excellent growing season. Some drought occurred in July and August which reduced yields of corn at Cambridge.

No sewage sludge or ammonium nitrate was applied to the Milton site in 1975 and the trial was abandoned at the end of the season at the farmer's request.

Each year that the program continues the results appear to become more interesting as clearer pictures develop on the effect of sludge application on soils and crops.

2. OBJECTIVES

The objective of this research is to determine maximum rates of sewage sludge application which can be used on agricultural soils without contaminating subsurface water with nitrate nitrogen and surface waters with elements or organisms pathogenic to humans and animals, and without reducing the yield or quality of the crops produced.

3. RUNOFF

3.1 Objectives

This section of the sludge project was designed to determine rates of sewage sludge which may be safely applied to certain slopes at specified times of the year.

3.2 Experimental

3.2.1 Design

Runoff was measured at the Elora Research Station on an imperfect to poorly drained sandy clay loam soil with systematic tile drains. Field plots, .025 ac (0.01 hectare) on 2% and 6% slope with suitable edging and runoff collection devices, were installed in the fall of 1972. Fluid iron precipitated sludge from the North Toronto sewage treatment plant was applied to separate plots each November, January and May.

Rates of application based on the nitrogen content of the sludge were 178 lb N/ac (200 kg N/ha) and 712 lb N/ac (800 kg N/ha) on the 2% slope and 178 lb N/ac (200 kg N/ha) on the 6% slope. On each slope the treatment without sludge received 100 lb N/ac (112 kg N/ha) as ammonium nitrate (NH_4NO_3) in the spring. There were two replicates of each treatment.

After each runoff event the volumes of water collected were measured, samples taken and tanks emptied.

The spring sludge and fertilizer applications were made on May 2, 1975, and ploughing and corn planting were completed by May 14, 1975. The corn was harvested on October 14, 1975.

3.2.2 Water analysis

Soluble nitrogen and phosphorus in the water samples were determined directly using an automated procedure after passing through a 0.45 μ filter. Total nitrogen and phosphorus in the unfiltered water samples were determined using an automated procedure after digestion with H_2SO_4-H_2O_2 (Thomas, et al., 1967).

Soluble metals, cadmium (Cd), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn) were determined by atomic absorption after the water samples were passed through a 0.45 μ filter, chelated with APDC[1] and extracted with MIBK[2]. Acid extractable metals were determined by digesting unfiltered water samples with aqua regia; the concentrations were determined by atomic absorption.

Mercury content of filtered (0.45 μ) water samples was determined by flameless atomic absorption (Hamm and Stewart, 1973) after oxidation of the organic mercurials with potassium permanganate and potassium persulphate. Sediment collected on the filters was digested with aqua regia at 60°C before mercury determination by flameless atomic absorption.

3.3 Results and Discussion

3.3.1 Crop yield

Germination was normal and after thinning to 20,000 plants per acre on June 17, the corn was harvested on October 14. The yields are given in Table 1. In general, yields on the 2% slope were higher from sludge (regardless of rate) than from 112 kg N per ha from commercial sources, and were higher than yields of all treatments on the 6% slope. There was little difference in yield between different times of application within each slope, and within each rate of application. Yields for all treatments were considerably higher than the yields in either 1974 or 1973.

3.3.2 Precipitation and runoff losses

Total precipitation for the three runoff periods ending Jan. 19, 1976 (Tables 3, 4, 5) was 92.2 cm. This is 12.8 cm higher than the previous 12-month period ending Dec. 31, 1974, and 6.4 cm more than the 30-year average for this region (Table 2). Twelve runoff events occurred following the winter application of sludge (Jan. 15), (Table 3) and three runoff events occurred following the spring application of sludge - one each in June (18th), July (20th) and Aug. (25th), (Table 4). The last two were each caused by less than 50 mm of precipitation. There was insufficient precipitation to cause runoff following the fall application of sludge (Nov. 20), (Table 5). Several of the March and April events were due to snowmelt. The largest single total precipitation event since 1973 occurred Aug. 23 (Table 4), but it came slowly enough, and the vegetation was sufficiently advanced that no runoff occurred. Runoff did occur with short, intense rainfall events, especially when the soil moisture was already high from preceding rainfall events.

---

[1] Pyrrolidine carbodithioc acid ammonium salt

[2] Methyl isobutyl ketone

The highest June rainfall for a 24-hour period since 1973 occurred in 1975 (39 mm), (Table 4). It did cause runoff, and events greater than this can be expected five times over a 30-year period (Table 6). No intense rainfall events occurred during July since this experiment commenced, but events greater than those experienced can occur 12 times over a 30-year period (Table 6).

The volumes of runoff collected during the year are indicated in Tables 7, 8, 9 and 10. Total runoff in 1975 was similar to that in the previous two years of the experiment. As in other years, several times more runoff occurred during winter months (Table 7) than during other periods of the year. The steeper slope did not increase runoff in winter months, but did increase losses by roughly one-half during summer months (Table 9). There is little evidence that sludge has a real effect on runoff volume (Tables 7, 9). The fall period in 1975 gave no runoff.

The losses of total and soluble nitrogen and phosphorus are shown in Tables 7, 8, 9, 10. The amounts of N and P and metals in runoff in 1975 were also similar to other years. The greatest apparent loss of sludge N and P was during winter months from plots treated with sludge in January at the beginning of the winter period. Losses were high during summer on the six percent slope for all times of application including conventionally fertilized soil without sludge. Although precipitation coincided with sludge applications in 1975 and 1976, it was not sufficient to cause immediate runoff as occurred in 1974.

The soluble heavy metal losses were in general very small (Tables 11, 12). Soluble heavy metal losses were greatest during the winter months, with little difference in many cases between different rates or times of application. Losses of some metals (e.g. Zn and Pb) were greater on the 6% slope than on the 2% slope. Losses of acid-extractable metals were several-fold higher than metals in solution, the greater differences occurring with the summer losses (Tables 13 and 14). This reflects the much greater metal content associated with solid material, which in turn is associated more with summer runoff.

An estimate of the amount of organic material present in runoff water is given by the value of the chemical oxygen demand (Table 15). The variability in chemical oxygen demand (COD) makes it difficult to establish trends, but it appears that sludge does not increase amounts significantly. The lack of immediate runoff following sludge application may have prevented such increases.

3.4 Conclusions

The rainfall pattern since 1973 has probably not provided for the maximum amount of runoff which might be expected over a 30-year period. Nutrient losses and COD was lower in 1975 than in 1974 due in part to lack of runoff immediately following sludge application.

The greatest loss of water continues to occur in winter periods, but similar losses of nutrients can occur in both summer and winter, depending on sludge treatment and soil slope.

Corn yields in 1975 were the highest of the three years of the study, with little difference due to different sludge application methods. Yields with conventional fertilizer were lower than those where sludge was used.

3.5 Literature Cited

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2. Thomas, R.L., R.W. Sheard and J.R. Moyer. 1967. Comparison of conventional and automated procedures for nitrogen, phosphorus and potassium analysis of plant material using a single digest. Agron J. 59: 240-243.

TABLE 1. Yields of Corn (Shelled Grain*) in 1973, 1974, and 1975.

Slope and treatment		1973		1974 lb/ac (kg/ha)		1975	
6% slope							
200 kg N	Fall	4390	(4920)	4600	(5150)	7210	(8070)
	Winter	4010	(4490)	4450	(4990)	6690	(7490)
	Spring	4200	(4700)	4510	(5050)	6736	(7540)
	Check	4190	(4690)	4640	(5200)	6800	(7620)
2% slope							
200 kg N	Fall	4480	(5020)	6280	(7040)	8040	(9000)
	Winter	3610	(4040)	6090	(6820)	7860	(8800)
	Spring	4390	(4920)	5250	(5880)	8090	(9060)
800 kg N	Fall	6030	(6750)	5070	(5670)	7860	(8800)
	Winter	5760	(6450)	4810	(5390)	7970	(8930)
	Spring	5690	(6370)	5580	(6250)	8090	(9060)
	Check	4270	(4780)	4900	(5490)	7620	(8530)

* 15% moisture

TABLE 2. Monthly and Cumulative Precipitation for the Elora Research Station, 1975.

	January 1975 - December 1975				30-year Average			
Month	Monthly total		Cumulative total		Monthly total		Cumulative total	
	in	(cm)	in	(cm)	in	(cm)	in	(cm)
January	2.35	5.97	2.35	5.97	2.79	7.08	2.79	7.08
February	3.34	8.48	5.69	14.45	2.24	5.69	5.03	12.77
March	2.63	6.68	8.32	21.13	2.48	6.30	7.51	19.07
April	3.71	9.42	12.03	30.55	2.70	6.86	10.21	25.93
May	2.00	5.08	14.03	35.63	3.10	7.87	13.31	33.80
June	4.33	10.99	18.36	46.62	3.00	7.62	16.31	41.42
July	2.35	5.97	20.71	52.59	3.10	7.87	19.41	49.29
August	5.55	14.10	26.26	66.69	3.10	7.87	22.51	57.16
September	2.18	5.54	28.44	72.23	3.00	7.62	25.51	64.78
October	1.64	4.17	30.08	76.40	2.79	7.08	28.30	71.85
November	1.90	4.83	31.98	81.23	2.70	6.86	31.00	78.72
December	3.01	7.65	34.99	88.88	2.79	7.08	33.79	85.80

TABLE 3. Rainfall in Winter Period, Elora. January 15, 1975 to May 1, 1975.

Day of Month	January in	January cm	February in	February cm	March in	March cm	April in	April cm	May in	May cm
1					0.02	0.05	0.04	0.10		
2							0.98	2.49		
3							0.34	0.86		
4			0.01	0.03			0.01	0.03		
5			0.20	0.51	0.25	0.64				
6			0.04	0.10	0.02	0.05				
7			0.02	0.05	0.44	1.12				
8			0.01	0.03						
9			0.01	0.03						
10			0.04	0.10			———	———		
11			0.04	0.10	0.01	0.03				
12			0.12	0.30	$\underline{0.10}$	$\underline{0.25}$				
13			0.09	0.23	———	———				
14			0.02	0.05	0.09	0.23	———	———		
15	$\boxed{0.09}$	$\boxed{0.23}$	0.19	0.48						
16	0.08	0.20								
17	0.11	0.28	0.39	0.99			0.06	0.15		
18	0.03	0.08	0.30	0.76	$\underline{0.07}$	$\underline{0.18}$	1.98	5.03		
19					$\underline{0.43}$	$\underline{1.09}$	0.07	0.18		
20										
21					0.02	0.05	———	———		
22			0.17	0.43	0.49	1.24				
23			$\underline{0.77}$	$\underline{1.96}$	$\underline{0.15}$	$\underline{0.38}$	0.20	0.51		
24	0.16	0.41	$\underline{0.55}$	$\underline{1.40}$	0.08	0.20				
25	0.45	1.14	$\underline{0.20}$	$\underline{0.51}$	0.06	0.15				
26	0.02	0.05	0.11	0.28						
27			0.02	0.05						
28	0.46	1.17	0.04	0.10	0.14	0.36				
29	0.07	0.18			0.09	0.23				
30	$\underline{0.02}$	$\underline{0.05}$			0.11	0.28	0.03	0.08		
31					0.06	0.15				
Monthly Total	0.68	1.73	3.34	8.48	2.63	6.68	3.71	9.42		
Cumulative Total			4.02	10.21	6.65	16.89	10.36	26.31		

☐ Denotes a date of sludge application

——— Denotes a date on which a runoff occurred

TABLE 4. Rainfall in Summer Period, Elora. May 2, 1975 to November 19, 1975.

Day of Month	May		June		July		August	
	in	cm	in	cm	in	cm	in	cm
1								
2	☐	☐	0.01	0.03	T	T	0.62	1.57
3	0.27	0.69					0.40	1.02
4	0.12	0.30	0.39	0.99				
5	0.34	0.86	0.18	0.46			0.01	0.03
6	0.24	0.61					T	T
7					0.07	0.18		
8								
9								
10					0.09	0.23	0.14	0.36
11			0.52	1.32				
12	0.13	0.33	0.01	0.03			0.04	0.10
13			T	T	0.62	1.57	0.24	0.61
14			0.05	0.13				
15			0.66	1.68				
16								
17			0.36	0.91				
18			1.55	3.94	0.65	1.65		
19					0.27	0.69		
20					0.19	0.48		
21							0.56	1.42
22								
23			0.03	0.08	0.14	0.36	2.31	5.87
24	0.11	0.28	0.57	1.45			0.19	0.48
25	0.27	0.69					0.14	0.36
26	0.12	0.30					T	T
27					0.32	0.81		
28								
29							0.68	1.73
30	0.20	0.51					T	T
31	0.20	0.51					0.22	0.56
Monthly Total	2.00	5.08	4.33	11.00	2.35	5.97	5.55	14.10
Cumulative Total			6.33	16.08	8.68	22.05	14.35	36.14

☐ Denotes a date of sludge application

___ Denotes a date on which a runoff occurred

T Denotes trace (<0.01 in)

TABLE 4. (Continued)

Day of Month	September		October		November	
	in	cm	in	cm	in	cm
1	0.01	0.03	0.07	0.18	0.03	0.08
2					0.22	0.56
3					0.23	0.58
4						
5	0.13	0.33				
6	0.01	0.03			0.04	1.10
7	0.10	0.03			0.05	0.13
8			T	T		
9			0.04	0.10	0.41	1.04
10	T	T	0.02	0.05	0.10	0.30
11	0.42	1.07	0.06	0.15	0.02	0.05
12			0.14	0.36		
13	0.15	0.38	0.55	1.40		
14	0.01	0.03				
15						
16					T	T
17	T	T	0.14	0.36		
18	0.78	1.98				
19	0.38	0.97	0.49	1.24		
20						
21	0.13	0.33				
22						
23						
24	T	T				
25	0.02	0.05	0.03	0.08		
26	T	T				
27						
28						
29	0.04	0.10				
30	T	T				
31			0.10	0.30		
Monthly Total	3.16	8.03	1.64	4.17	1.10	2.79
Cumulative Total	17.39	44.17	19.03	48.34	20.13	51.13

☐	Denotes a date of sludge application
___	Denotes a date on which a runoff occurred
T	Denotes trace (<0.01 in)

TABLE 5. Rainfall in Fall Period, Elora. November 20, 1975 to January 19, 1976.

Day of Month	November in	November cm	December in	December cm	January in	January cm
1			0.08	0.20		
2			0.44	1.12	T	T
3			0.07	0.18	0.11	0.28
4			T	T	0.03	0.08
5			0.36	0.91		
6					0.30	0.76
7					0.01	0.03
8			0.15	0.38	0.04	0.10
9			0.23	0.58	0.03	0.08
10					0.25	0.64
11					0.20	0.51
12						
13			0.05	0.13	0.52	1.32
14			0.30	0.76	0.04	0.10
15					0.28	0.71
16			0.06	0.15	0.02	0.05
17			0.03	0.08		
18			0.18	0.46		
19			0.15	0.38	0.16	0.41
20	0.20	0.51	0.20	0.51		
21	0.03	0.08				
22	T	T	0.02	0.05		
23			T	T		
24	T	T	T	T		
25	0.05	0.13	0.19	0.48		
26	0.20	0.51	0.06	0.15		
27	0.02	0.05	0.01	0.03		
28			0.01	0.03		
29	0.06	0.15	0.30	0.76		
30	0.24	0.61	0.12	0.30		
Monthly Total	0.80	2.03	3.01	7.65	1.99	5.07
Cumulative Total			3.81	9.68	5.80	14.75

☐ Denotes a date of sludge application

— Denotes a date on which a runoff occurred

T Denotes trace (<0.01 in)

TABLE 6. Maximum Rainfall Recorded in a 24 hour Period of Each Summer Month (April to September), 1973-1975 and the Probability of its Occurrence.

	April	May	June	July	Aug.	Sept.
24 hour period maximum amount - inches	1.98	2.02	1.60	1.17	2.31	.78
Year of event	1975	1974	1975	1973	1975	1975
Events exceeding the amount/30 yrs.	1	1	5	12	1	18
Maximum /30 years - inches	6.04	2.60	2.35	2.84	4.07	2.04

TABLE 7. Runoff Losses in Winter Period, January 15 - May 1, 1975. Total Nitrogen and Phosphorus.

Slope and Treatment		Runoff in	(cm)	Nitrogen lb/ac	(kg/ha)	Phosphorus lb/ac	(kg/ha)
6% Slope							
200 kg N	Fall	6.02	(15.3)	3.22	(3.61)	0.55	(0.62)
	Winter	6.36	(16.2)	9.03	(10.1)	1.37	(1.54)
	Spring	6.36	(16.2)	2.18	(2.44)	0.36	(0.41)
	Check	5.36	(13.6)	1.72	(1.93)	0.25	(0.29)
2% Slope							
200 kg N	Fall	5.92	(15.0)	2.52	(2.83)	0.34	(0.38)
	Winter	4.02	(10.2)	2.63	(2.95)	0.50	(0.56)
	Spring	4.44	(11.3)	2.33	(2.62)	0.48	(0.53)
800 kg N	Fall	6.21	(15.8)	5.37	(6.02)	0.50	(0.56)
	Winter	5.60	(14.2)	6.66	(7.47)	0.81	(0.91)
	Spring	5.65	(14.4)	2.09	(2.35)	0.32	(0.35)
	Check	4.07	(10.3)	1.90	(2.13)	0.28	(0.31)

TABLE 8. Runoff Losses in Winter Period, January 15 - May 1, 1975. Soluble Nitrogen and Phosphorus.

Slope and Treatment		Runoff in	(cm)	Nitrogen lb/ac	(kg/ha)	Phosphorus lb/ac	(kg/ha
6% Slope							
200 kg N	Fall	6.02	(15.3)	2.55	(2.87)	0.53	(0.60)
	Winter	6.36	(16.2)	8.15	(9.15)	0.64	(0.72)
	Spring	6.36	(16.2)	1.16	(1.30)	0.18	(0.20)
	Check	5.36	(13.6)	1.06	(1.19)	0.19	(0.21)
2% Slope							
200 kg N	Fall	5.92	(15.0)	2.23	(2.50)	0.23	(0.26)
	Winter	4.02	(10.2)	1.87	(2.09)	0.21	(0.24)
	Spring	4.44	(11.3)	1.27	(1.43)	0.21	(0.23)
800 Kg N	Fall	6.21	(15.8)	5.23	(5.87)	0.26	(0.29)
	Winter	5.60	(14.2)	5.50	(6.18)	0.30	(0.33)
	Spring	5.65	(14.4)	1.66	(1.86)	0.15	(0.17)
	Check	4.07	(10.3)	1.16	(1.30)	0.20	(0.23)

TABLE 9. Runoff Losses in Summer Period, May 2 - November 19, 1975. Total Nitrogen and Phosphorus.

Slope and Treatment		Runoff in	(cm)	Nitrogen lb/ac	(kg/ha)	Phosphorus lb/ac	(kg/ha)
6% Slope							
200 kg N	Fall	1.57	(3.99)	10.86	(12.17)	3.90	(4.37)
	Winter	1.58	(4.01)	7.86	(8.82)	2.61	(2.93)
	Spring	1.68	(4.27)	9.27	(10.39)	3.77	(4.22)
	Check	1.57	(3.99)	7.65	(8.58)	2.69	(3.02)
2% Slope							
200 kg N	Fall	0.88	(2.24)	1.07	(1.20)	0.38	(0.42)
	Winter	1.09	(2.77)	1.65	(1.85)	0.65	(0.73)
	Spring	1.05	(2.67)	2.07	(2.32)	0.72	(0.80)
800 kg N	Fall	1.08	(2.74	3.27	(3.66)	1.30	(1.46)
	Winter	1.10	(2.79)	2.48	(2.78)	1.02	(1.14)
	Spring	1.18	(3.00)	3.77	(4.23)	1.53	(1.72)
	Check	1.24	(3.15)	3.31	(3.70)	1.12	(1.25)

TABLE 10. Runoff Losses in Summer Period, May 2 - November 19, 1975. Soluble Nitrogen and Phosphorus.

Slope and Treatment		Runoff in	(cm)	Nitrogen lb/ac	(kg/ha)	Phosphorus lb/ac	(kg/ha)
6% Slope							
200 kg N	Fall	1.57	(3.99)	0.128	(0.144)	0.037	(0.041)
	Winter	1.58	(4.01)	0.160	(0.180)	0.037	(0.041)
	Spring	1.68	(4.27	0.184	(0.207)	0.045	(0.051)
	Check	1.57	(3.99)	0.108	(0.121)	0.040	(0.045)
2% Slope							
200 kg N	Fall	0.88	(2.24)	0.080	(0.090)	0.021	(0.024)
	Winter	1.09	(2.77)	0.075	(0.084)	0.023	(0.026)
	Spring	1.05	(2.67)	0.083	(0.093)	0.020	(0.022)
800 kg N	Fall	1.08	(2.74)	0.074	(0.083)	0.024	(0.027)
	Winter	1.10	(2.79)	0.076	(0.085)	0.025	(0.028)
	Spring	1.18	(3.00)	0.081	(0.091)	0.029	(0.033)
	Check	1.24	(3.15)	0.099	(0.112)	0.023	(0.026)

TABLE 11. Soluble Metals in Runoff - Winter 1975

Slope and Treatment		Cd	Cu	Hg	Ni	Pb	Zn
		lb/ac x 10^{-3} (Kg/ha x 10^{-3})					
6% Slope							
200 Kg N							
	Fall	0.8 (0.9)	8.1 (9.1)	0.3 (0.3)	3.3 (3.7)	11.6 (13.0)	64.0 (71.7)
	Winter	0.9 (1.0)	15.8 (17.7)	0.3 (0.3)	3.7 (4.1)	22.6 (25.3)	92.2 (103.3)
	Spring	0.4 (0.4)	3.8 (4.3)	0.2 (0.2)	1.3 (1.5)	16.2 (18.1)	50.6 (56.7)
	Check	0.3 (0.3)	4.9 (5.5)	0.2 (0.2)	0.9 (1.0)	6.5 (7.3)	21.2 (23.7)
2% Slope							
200 Kg N							
	Fall	0.4 (0.4)	10.1 (11.3)	0.4 (0.4)	2.7 (3.0)	10.7 (12.0)	38.1 (42.7)
	Winter	0.4 (0.4)	7.0 (7.8)	0.2 (0.2)	4.1 (4.6)	13.0 (14.6)	25.5 (28.6)
	Spring	0.2 (0.2)	7.0 (7.8)	0.1 (0.1)	1.5 (1.7)	7.9 (8.8)	33.7 (37.7)
800 Kg N							
	Fall	0.4 (0.4)	12.6 (14.1)	0.3 (0.3)	3.5 (3.9)	13.3 (14.9)	50.6 (56.7)
	Winter	0.3 (0.3)	18.4 (20.6)	0.3 (0.3)	4.4 (4.9)	16.0 (17.9)	35.8 (40.1)
	Spring	0.2 (0.2)	7.8 (8.7)	0.3 (0.3)	2.6 (2.9)	12.3 (13.8)	33.8 (37.9)
	Check	0.2 (0.2)	5.5 (6.2)	0.3 (0.3)	1.4 (1.6)	12.0 (13.4)	29.3 (32.8)

TABLE 12. Soluble Metals in Runoff - Summer 1975

Slope and Treatment		Cd		Cu		Hg		Ni		Pb		Zn	
		lb/ac x 10^{-3} (Kg/ha x 10^{-3})											
6% Slope													
200 Kg N													
	Fall	<0.02	(<0.02)	2.6	(2.9)	0.2	(0.2)	<0.02	(<0.02)	<0.2	(<0.2)	0.2	(0.2)
	Winter	<0.02	(<0.02)	2.3	(2.6)	0.2	(0.2)	<0.02	(<0.02)	<0.2	(<0.2)	0.3	(0.3)
	Spring	<0.02	(<0.02)	1.7	(1.9)	0.2	(0.2)	<0.02	(<0.02)	<0.2	(<0.2)	1.0	(1.1)
	Check	<0.02	(<0.02)	1.3	(1.5)	0.2	(0.2)	<0.02	(<0.02)	<0.2	(<0.2)	0.1	(0.1)
2% Slope													
200 Kg N													
	Fall	<0.02	(<0.02)	2.7	(3.0)	0.1	(0.1)	<0.02	(<0.02)	<0.2	(<0.2)	0.2	(0.2)
	Winter	<0.02	(<0.02)	3.2	(3.6)	0.2	(0.2)	<0.02	(<0.02)	<0.2	(<0.2	0.3	(0.3)
	Spring	<0.02	(<0.02)	1.4	(1.6)	0.2	(0.2)	<0.02	(<0.02)	<0.2	(<0.2)	0.3	(0.3)
800 Kg N													
	Fall	<0.02	(<0.02)	2.3	(2.6)	0.1	(0.1)	<0.02	(<0.02)	<0.2	(<0.2)	0.6	(0.7)
	Winter	<0.02	(<0.02)	2.8	(3.1)	0.3	(0.3)	<0.02	(<0.02)	<0.2	(<0.2)	1.1	(1.2)
	Spring	<0.02	(<0.02)	2.5	(2.8)	0.2	(0.2)	<0.02	(<0.02)	<0.2	(<0.2)	1.6	(1.8)
	Check	<0.02	(<0.02)	1.2	(1.3)	0.1	(0.1)	<0.02	(<0.02)	<0.2	(<0.2)	0.2	(0.2)

TABLE 13. Acid-extractable Metals in Runoff - Winter 1975

Slope and Treatment		Cd	Cu	Hg*	Ni	Pb	Zn
		lb/ac x 10^{-3} (kg/ha x 10^{-3})					
6% Slope							
200 kg N							
	Fall	2.3 (2.6)	36.8 (41.2)	0.6 (0.7)	28.7 (32.1)	86 (96)	245 (274)
	Winter	2.9 (3.2)	58.0 (65.0)	0.8 (0.9)	25.4 (28.4)	119 (133)	260 (291)
	Spring	1.5 (1.7)	20.9 (23.4)	0.4 (0.4)	20.9 (23.4)	56 (63)	137 (154)
	Check	1.9 (2.1)	36.6 (41.4)	0.4 (0.4)	29.3 (32.8)	92 (103)	238 (266)
2% Slope							
200 kg N							
	Fall	1.3 (1.5)	12.7 (14.2)	1.0 (1.1)	13.4 (15.0)	26 (29)	75 (84)
	Winter	0.9 (1.0)	11.2 (12.5)	0.4 (0.4)	10.3 (11.5)	34 (38)	56 (63)
	Spring	1.0 (1.1)	12.9 (14.4)	0.2 (0.2)	11.9 (13.3)	40 (45)	85 (95)
800 kg N							
	Fall	1.4 (1.6)	19.6 (22.0)	0.7 (0.8)	21.7 (24.3)	41 (46)	113 (127)
	Winter	1.3 (1.5)	33.4 (37.4)	2.0 (2.2)	11.7 (13.1)	30 (34)	101 (114)
	Spring	1.3 (1.5)	12.3 (13.8)	0.8 (0.9)	12.3 (13.8)	25 (28)	94 (105)
	Check	0.9 (1.0)	9.2 (10.3)	2.1 (2.3)	7.4 (8.3)	32 (36)	68 (76)

* Sum of Hg in filtered (0.45 μ) water samples and in sediments.

TABLE 14. Acid-extractable Metals in Runoff - Summer 1975

Slope and Treatment		Cd	Cu	Hg*	Ni	Pb	Zn
		lb/ac x 10^{-3} (kg/ha x 10^{-3})					
6% Slope							
200 Kg N							
	Fall	3.0 (3.4)	53.4 (59.8)	0.4 (0.4)	52 (58)	98 (110)	133 (149)
	Winter	3.2 (3.6)	16.8 (18.8)	0.6 (0.7)	60 (67)	104 (116)	151 (169)
	Spring	2.4 (2.7)	22.4 (25.1)	0.4 (0.4)	48 (54)	113 (126)	91 (102)
	Check	2.1 (2.4)	35.2 (39.4)	0.3 (0.3)	32 (36)	40 (45)	68 (75)
2% Slope							
200 Kg N							
	Fall	1.3 (1.5)	8.2 (9.2)	0.3 (0.3)	27 (31)	49 (55)	74 (83)
	Winter	1.2 (1.3)	2.8 (3.1)	0.4 (0.4)	15 (16)	31 (35)	28 (31)
	Spring	1.5 (1.7)	6.7 (7.5)	0.5 (0.6)	31 (35)	70 (78)	29 (32)
800 Kg N							
	Fall	2.0 (2.2)	15.8 (17.7)	0.5 (0.6)	41 (46)	76 (85)	91 (102)
	Winter	1.9 (2.1)	24.3 (27.2)	0.6 (0.7)	37 (41)	83 (93)	116 (130)
	Spring	2.3 (2.6)	29.1 (32.6)	0.7 (0.8)	55 (62)	97 (109)	132 (148)
	Check	1.1 (1.2)	11.4 (12.8)	0.2 (0.2)	32 (35)	39 (44)	56 (62)

* Sum of Hg in filtered (0.45 µ) water samples and in sediments.

TABLE 15. COD in Runoff Water for Winter and Summer Periods, 1975.

Slope and treatment		Winter lb/ac (kg/ha)		Summer lb/ac (kg/ha)	
6% Slope					
200 kg N	Fall	121	(136)	227	(255)
	Winter	200	(225)	246	(276)
	Spring	38	(42)	181	(203)
	Check	102	(114)	249	(279)
2% Slope					
200 kg N	Fall	160	(179)	37	(42)
	Winter	45	(51)	157	(175)
	Spring	52	(59)	75	(85)
800 kg N	Fall	113	(126)	110	(123)
	Winter	105	(118)	90	(101)
	Spring	116	(130)	87	(97)
	Check	65	(73)	167	(187)

4. FIELD RATE AND SOURCE EXPERIMENTS

4.1 Objectives

The objective of the field rate and source experiments is to determine the rate of three chemically treated sludges which may be safely used on typical Ontario soils without adversely affecting crop yields or nitrate, and heavy metal contents.

4.2 Materials and Methods

4.2.1 General

Experiments are in progress on three soils: (1) Conestoga loam to sandy clay loam on the Elora Research Station, (2) Caledon loamy sand on the Cambridge (Hespeler) Research Station, (3) Oneida clay loam on the farm of David Sargent near Milton. At the Elora Research Station one experiment is in progress with corn (*Zea mays* L.) as the crop and one with bromegrass (*Bromis inermis Leyess*). Only corn is being grown at the Cambridge and Milton sites. The Milton site received no sludge or nitrogen in 1975.

The following sources of nitrogen have been used:

(1) ammonium nitrate
(2) fluid digested calcium treated sludge from the Newmarket treatment plant,
(3) fluid digested aluminum sulphate treated sludge from the Point Edward (1973) and Kitchener (1974 & 1975) treatment plants,
(4) fluid digested ferric chloride treated sludge from the North Toronto treatment plant.

The rates of nitrogen application each year from the sludges are:

(1) 178 lb N/ac (200 kg/ha)
(2) 356 lb N/ac (400 kg/ha)
(3) 712 lb N/ac (800 kg/ha)
(4) 1424 lb N/ac (1600 kg/ha)

The rates of nitrogen application each year from ammonium nitrate are:

(1) 0 lb N/ac
(2) 89 lb N/ac (100 kg/ha)
(3) 178 lb N/ac (200 kg/ha)
(4) 356 lb N/ac (400 kg/ha)

There are four nitrogen sources, four rates, and three replications resulting in a total of 48 plots for each trial. The corn plot size is 15' x 25' (4.57 x 7.62 m) and the bromegrass plot size is 8' x 20' (2.44 x 6.09 m).

Chemical composition of the Newmarket, Kitchener and North Toronto sewage sludges obtained at different times through the season are presented in Tables 16 and 17.

4.2.2 Bromegrass, Elora

The grass trial was laid out on an established stand of bromegrass on the Elora research station on Conestoga sandy clay loam in the spring of 1973. Potassium chloride supplying 50 lb of K_2O/ac (47 kg/ha) was broadcast on all plots in the spring of 1973 and supplying 97 lb of K_2O/ac (90 kg K/ha) in the spring of 1974 and again in 1975. Eighty-three lb P_2O_5/ac (40 kg P/ha) as 46% superphosphate was broadcast on the plots which received NH_4NO_3 fertilizer in the spring of 1973 and 80 lb P_2O_5/ac (39 kg P/ha) in the spring of 1974 and 83 lb P_2O_5/ac (40 kg P/ha) in the spring of 1975. The dates of nitrogen and sludge application to grass and harvest dates are presented in Table 18.

4.3 Results and Discussion

In general only 1975 data are discussed in this report as the 1974 results are available in the 1974 report. Corn yields over the three year period are presented, however, and soil tests taken in the fall of 1974 are presented as they were not available in time for the 1974 report. With the exception of crop yields, data are only presented where there are significant treatment effects.

4.3.1 Bromegrass

Total amounts of nutrients and metals applied in the sludge at rates supplying 178 lb N/ac (200 kg/ha) are presented in Table 19 and total amounts supplied in all three years in Table 20.

Total yields of bromegrass from the grass experiment as harvested in three consecutive cuttings in 1975 and for the 1974 season are presented in Tables 21, 22, 23, 24 and 25. Yield increased with each increase in rate of ammonium nitrate or with sewage sludge. The sludge resulting from lime treatment of sewage produced lower yields at low rates of application, but higher yields at higher rates of application, than the other sludges in both 1974 and 1975 (Tables 25 and 21). In 1973 the aluminum sludge from Point Edward produced lower yields than the other two sludges. The aluminum sludge used in 1974 and 1975 was from Kitchener and produced yields very similar to those with the iron sludge. Any undesirable effects of the Point Edward sludge apparently dissipated before the 1974 growing season.

Total nitrogen concentration in all three cuts of bromegrass was markedly increased by all sources of nitrogen, Tables 26, 27 and 28, as was nitrate nitrogen concentration, Tables 29, 30 and 31. The total nitrogen and nitrate nitrogen concentrations in bromegrass tended to be lower with the calcium sludge than with the other sludges. Nitrate nitrogen approached toxic levels for animals at the highest rate of sludge application in both 1974 and 1975.

Phosphorus concentration in the bromegrass was reduced by all sources of nitrogen in 1974 and in the first two cuts in 1975 (Tables 32 and 33) but the reverse was true in the third cut in 1975 (Table 34). Sewage sludge applications greatly increased the sodium bicarbonate-extractable phosphorus in the soil (Tables 35 and 36), the Ca sludge having by far the greatest effect and the Al sludge having the least effect. The Al sludge supplied appreciably less phosphorus than the Fe sludge but more than the Ca sludge (Table 19). The differences in sodium bicarbonate-extractable soil phosphorus did not appear to influence the P concentration in the bromegrass.

Potassium content of the first cut bromegrass was not affected by treatment. In 1974 and in the second and third cuts of 1975, potassium content was reduced by ammonium nitrate and by increasing rates of sludge (Tables 37 and 38), but in 1975 this was true only up to the 800 kg/ha rate of nitrogen. It is probable that the amount of potassium added at the 1600 kg N/ha rate from sludge overcame the effect of nitrogen on potassium concentration in the grass. The ammonium acetate-extractable soil potassium followed a rather similar pattern with treatment to that of potassium concentration in bromegrass (Tables 39 and 40).

Soil pH was increased by application of Ca sludge and decreased slightly by application of the Fe sludge (Tables 41 and 42). Ammonium nitrate decreased soil pH in 1974, but this effect was not apparent in the fall of 1975. Ammonium acetate-extractable calcium in the soil followed the similar pattern as soil pH with the Ca sludge increasing the concentration and the Fe sludge appearing to produce a small decrease (Table 43).

Calcium concentration in the first two cuts of bromegrass was increased by application of nitrogen from ammonium nitrate or from sludge (Tables 44 and 45), but source of sludge had no effect in spite of the large differences in amount of calcium added.

Magnesium extracted with ammonium acetate was greatest with the Fe sludge and least with the Ca sludge (Table 46). The Fe sludge also provided higher Mg concentration in all three cuts of bromegrass in 1975 (Tables 47, 48 and 49). Magnesium concentration increased with rate of nitrogen from ammonium nitrate or from sludge.

Aluminum concentration in the third cut of bromegrass was decreased by application of nitrogen from ammonium nitrate or from sludge (Table 50). It is possible that this was due to greater contamination of the lower yielding low nitrogen treatments by soil splash. The aluminum content of the first and second cuts was not affected by sludge applications.

Iron concentration in the first cut of bromegrass was increased by nitrogen application from ammonium nitrate or sludge (Table 51), but this pattern was reversed in the third cut (Table 52). The pattern in the third cut may be due to soil splash causing contamination on the low yielding low nitrogen treatments as was suggested with aluminum.

Manganese concentration was higher in bromegrass fertilized with ammonium nitrate than in that fertilized with sludge in all three cuts

(Tables 53, 54 and 55). Other treatment effects were not consistent from one cut to the next.

Cadmium concentration in the second and third cuts of bromegrass increased with increasing rate of sludge application (Tables 56, 57 and 58). This was most marked with the Fe sludge and in the third cut where Fe sludge at the highest rate more than doubled the cadmium concentration (Tables 56 and 57) reflecting the much higher cadmium additions in the Fe sludge (Table 19).

Chromium concentration was not markedly affected by sludge application except by the Al sludge which resulted in higher Cr concentration in the second and third cuts (Tables 59 and 60).

Copper concentration in the bromegrass was increased by ammonium nitrate in all three cuts (Tables 61, 62 and 63), and by sewage sludge in the first two cuts. The Ca sludge resulted in lower copper concentrations than the other two sludges although the copper additions in the Ca and Al sludges were similar. Twice as much copper was added in the Fe sludge as in either of the others.

Nickel concentration in the bromegrass was increased slightly by all three sludges (Table 64), but this was most marked in the third cut with the Al and Fe sludges (Table 65). Nickel concentration in the third cut also increased with rate of sludge application.

Lead concentration in bromegrass was little affected by sludge application (Table 66).

Zinc concentration increased with rate of sludge application in all three cuts of bromegrass (Tables 67, 68 and 69), and increased with rates of ammonium nitrate in cuts one and three. The Fe sludge resulted in the highest zinc concentrations in cuts one and three but not in cut two.

Mercury, Molybdenum and Selenium were analyzed on all three cuts of bromegrass but only on selected treatments. Mercury concentration in the bromegrass does not appear to have been affected by treatment (Table 70). Molybdenum and selenium concentrations may have been increased slightly by Fe sludge application.

4.3.2 Corn

Field operations on the three corn trials are outlined in Table 71, and the total amounts of nutrients and metals applied to each of the three sites in the sewage sludges during 1975 and over the 1973 to 1975 period are presented in Tables 72, 73, 74, 75 and 76.

The 1975 season started with a wet April which resulted in a slight delay in starting spring work; May was warm and the crop started well. July and August were dry at times, but the drought did not appear to affect the crop at Elora to any marked extent. The corn at Cambridge grew very well early in the season, but on this sandy soil water became limiting and yields were low. The Milton crop also suffered from drought.

Corn seedling emergence was affected by nitrogen rate and source on the sandy loam site at Cambridge; the more nitrogen applied the more emergence was reduced (Table 77). The sludges had less effect than ammonium nitrate and the Ca sludge had less effect than the Fe and Al sludges. Seedling weight was affected by nitrogen source at Cambridge with the Al sludge producing lower dry matter yields than the other sludges but higher than ammonium nitrate (Table 78). At Elora corn seedling weights were highest with no nitrogen or with the highest rate of Ca and Fe sludge, results which are difficult to explain (Table 79).

Grain yields were excellent at Elora averaging 7545 kg/ha (approx 120 bu/acre), but quite poor at Cambridge (3315 kg/ha - 53 bu/ac), and good at Milton (6016 kg/ha - 95 bu/ac) (Tables 80, 81 and 82). Cambridge yields were obviously reduced by lack of moisture. Treatments had little effect on yield at Elora and Cambridge, not even showing a nitrogen response from ammonium nitrate. At Milton there were some significant effects at the 5% probability level but they are difficult to interpret. The sludges tended to produce higher yields than ammonium nitrate. Corn grain yields for the three years of experimentation are given in Table 83.

Corn stover yields also showed little effect from treatments (Tables 84, 85 and 86).

Lodging of corn (leaning and broken stalks at harvest) increased with nitrogen rate at Elora (Table 87). Lodging was greater with the Ca and Fe sludges than with NH_4NO_3 or Al sludge. At Milton in 1974, lodging was greatest with the Ca sludge. Reasons for these results are not known.

Total nitrogen concentration in corn seedlings from the Elora trial was highest where no nitrogen was applied (Table 88). At Cambridge nitrogen concentration was also high where no nitrogen was applied with the lowest rate of sludge yielding lower concentrations (Table 89). The Al sludge resulted in lower nitrogen concentrations than the other sludges at Elora and the Ca sludge at Cambridge. Nitrogen concentration in corn stover at harvest was lowest where no nitrogen was applied and increased with rate of ammonium nitrate at Elora but sludge treatments were not significantly different (Table 90). At Milton increasing rates of sludge and ammonium nitrate (none applied in 1975) increased nitrogen concentration in the corn stover (Table 91). A similar pattern was visible in the corn grain at Milton but only with NH_4NO_3 and the Al sludge (Table 92).

Nitrate nitrogen in corn stover increased with nitrogen rate at Elora although the effect was rather erratic across sludges and rates (Table 93). A similar pattern was apparent at Cambridge and Milton although it was not statistically significant at Cambridge (Tables 94 and 95).

Phosphorus extracted from the soils with sodium bicarbonate in the fall in 1974 and 1975 from the three sites is presented in Tables 96, 97, 98, 99 and 100. At all three sites sodium bicarbonate soluble phosphorus increased with increasing rate of sludge application, and was appreciably higher with the Ca sludge than with the Al or Fe sludges. At Elora and Cambridge the sodium bicarbonate soluble phosphorus increased from 1973 to 1974 and from 1974 to 1975, and at Milton from 1973 to 1974 (1974/75 report).

Phosphorus concentration in corn seedlings was highest with the Ca sludge at Elora (Table 101) but was not affected by sludge source at the other sites. At Cambridge phosphorus concentration in seedlings decreased with increasing rate of ammonium nitrate but increased with increasing rate of sludge (Table 102). Phosphorus concentrations in corn grain and stover were not affected by treatment.

Potassium extracted from the soil with ammonium acetate increased with increasing rate of sludge application at Elora in 1974 and 1975 (Tables 103 and 104), but not at Cambridge or Milton. Sludge had no effect on soil potassium at Cambridge (Table 105). Soil potassium was lowest with the Ca sludge at Milton in 1974 (Table 106). Potassium concentration in the corn seedlings and in the stover at Elora (Tables 88 and 107) and in corn seedlings at Milton (Table 108) were lower with the Ca sludge than with the other sludges. Larger amounts of potassium were supplied by the Ca sludge over the three-year period at Elora (Table 74).

Soil pH values at the three sites in the fall of 1974 and at Elora and Cambridge in the fall of 1975 are presented in Tables 109, 110, 111, 112 and 113. The Ca sludge raised soil pH but NH_4NO_3 and the Al and Fe sludges lowered soil pH at all sites.

Calcium extracted from the soil by ammonium acetate was highest with the Ca sludge at Elora and Cambridge in 1975 (Tables 114 and 115). Calcium concentration in corn seedlings at Elora and Milton were highest with the Ca sludge (Tables 88 and 116). Calcium in corn stover at Elora increased with increasing rate of sludge (Table 117).

Magnesium extracted from the soil by ammonium acetate was lower with the Ca sludge than with other sources of nitrogen at all three sites in 1974 (Tables 105, 118 and 119). Magnesium concentration in corn seedlings at Elora in 1975 decreased with increased rate of nitrogen (Table 120). The corn stover at Elora in 1975 showed increased concentrations of magnesium with increased rate of ammonium nitrate (Table 121).

Aluminum concentration in corn grain at Elora was highest with the Fe sludge in 1975 (Table 122). Aluminum concentrations in corn stover at Milton showed some significant treatment effects, but no rational pattern is apparent, and it is believed that soil contamination was probably a factor (Table 123).

Manganese concentration in corn grain at Milton increased with increasing rate of nitrogen from NH_4NO_3 or from Fe sludge (Table 124).

Cadmium concentration in corn stover at Elora increased with increasing rate of sludge application with the Fe sludge having a much greater effect than the Ca sludge (Table 125). The Al sludge was intermediate. The Fe sludge supplied at least seven times as much Ca as the other sludges (Table 74).

Chromium concentration in corn stover from Elora increased with increasing rate of sludge and was highest with the Al sludge (Table 126). Over ten times as much chromium was added in the Al sludge as in either of the others (Table 74).

Copper concentration in corn stover at Milton increased with increasing rate of nitrogen from sludge or ammonium nitrate (Table 127).

Lead concentration in corn stover at Elora was highest with the Fe sludge but did not appear to increase with increasing rate of sludge application (Table 128). The Fe sludge supplied approximately six times as much Pb as the other sludges (Table 74).

Zinc concentration in corn stover at Elora increased with increasing rate of sludge and this effect was most marked with the Fe sludge (Table 129). In the corn grain at Elora and Cambridge zinc concentration increased with increasing rate of sludge application (Tables 130 and 131). In the corn grain at Milton zinc concentration increased with rate of application of the Fe sludge but not with the Ca or Al sludges (Table 132). In the corn stover at Milton zinc concentration increased with rate of application of sludge and was lower with the Ca sludge than with the Al or Fe sludges (Table 133).

Molybdenum, mercury and selenium were determined on the corn grain and stover from selected treatments. There appears to have been an increase in molybdenum content of the grain and perhaps of the stover at the three sites where high rates of sludge were applied (Table 134).

Mercury concentrations in the corn grain and stover do not appear to be affected by treatment (Table 135).

Selenium concentrations in the corn grain and stover do not appear to be affected by treatment (Table 136).

Metals in soil water sampled at 45 and 90 cm depth in the fall of 1975 are presented in Table 137. Data have not been analyzed statistically but there appear to be some increases due to sludge application.

4.4 Conclusions

4.4.1 Bromegrass

The metal concentrations in bromegrass which were most consistently and markedly increased by sludge application were cadmium and zinc. Other metal concentrations were increased but care should be taken in interpreting these results as ammonium nitrate applications also frequently increased metal concentrations in the bromegrass.

Sludge applications did affect the concentrations of nitrogen, potassium, calcium, magnesium, aluminum, iron and manganese in the crop but with the exception of nitrogen, which increased nitrate content of the forage, no particular problem appears to have been created in regard to these elements.

4.4.2 Corn

Corn yields were little affected by treatment. This appears to be one of those seasons which occur occasionally. There was almost no nitrogen response to corn at these sites. Nitrogen additions did increase the nitrogen concentration in the crop to some extent.

Phosphorus extractable with sodium bicarbonate increased with sludge application, particularly with the Ca sludge. This is one of the most consistent effects of sludge application across trials and seasons. Probably because phosphorus concentrations in the plants are quite high a difference in phosphorus concentration in the plant due to treatments in these trials has rarely been found.

The effects of the sludges on metal concentration in the crop appear to be rather erratic, showing up in one tissue but not in another and in one site or another. Cadmium, chromium and lead in corn stover were increased at Elora only but were highest with the sludges supplying the largest amount of cadmium, chromium and lead respectively. It is not clear why these effects showed on the Elora site but not on the other sites.

Zinc concentration was increased in both stover and grain by sludge application on more than one site, although differences between sludges were not consistent.

Molybdenum in corn grain appears to have been increased by sludge application but not mercury or selenium.

TABLE 16. Chemical Composition of Sludges Obtained from Treatment Plants on Various Dates (fluid weight basis)

Sludge	Date	pH	D.M.	Total N	Soluble & Exch. NH_4-N	P	K	Ca	Mg	Na	Al	Fe
			%									
Calcium	24/4/75	6.8	8.3	0.19	0.037	0.088	0.022	1.16	0.035	0.024	0.031	0.063
Newmarket	9/6/75	7.1	8.3	0.17	0.035	0.090	0.016	1.45	0.035	0.019	0.022	0.042
	16/7/75	6.9	7.8	0.16	0.041	0.061	0.015	0.50	0.030	0.044	0.026	0.047
Aluminium	24/4/75	7.6	5.3	0.32	0.130	0.17	0.019	0.20	0.036	0.028	0.195	0.046
Kitchener	30/4/75	7.6	5.8	0.33	0.128	0.21	0.025	0.25	0.039	0.032	0.219	0.044
	3/6/75	7.7	4.9	0.27	0.110	0.17	0.026	0.31	0.033	0.039	0.185	0.044
	15/7/75	7.7	4.4	0.23	0.048	0.20	0.031	0.26	0.037	0.061	0.170	0.037
Iron	1/5/75	7.3	6.5	0.30	0.099	0.30	0.030	0.18	0.040	0.029	0.072	0.522
N. Toronto	2/5/75	7.3	6.5	0.30	0.093	0.29	0.031	0.17	0.035	0.035	0.071	0.533
	7/5/75	7.4	6.1	0.28	0.112	0.26	0.028	0.15	0.035	0.032	0.095	0.417
	10/6/75	7.2	5.5	0.31	0.092	0.29	0.031	0.20	0.044	0.023	0.065	0.446
	21/6/75	7.4	6.4	0.31	0.083	0.30	0.030	0.21	0.040	0.022	0.074	0.503

TABLE 17. Micronutrient and Metal Content of Sludges Obtained from Treatment Plants on Various Dates (fluid weight basis).

Sludge	Date	Cd	Cr	Cu	Hg	Mn	Mo	Ni	Pb	Se	Zn	B
		µg/g										
Calcium	24/4/75	0.2	2.6	17	0.24	48	0.52	3.6	14	0.012	86	0.7
Newmarket	9/6/75	0.2	1.9	17	0.18	34	0.62	1.5	12	0.12	62	1.3
	16/7/75	0.2	3.4	29	0.29	38	0.59	1.6	21	0.18	86	2.3
Aluminium	24/4/75	0.4	401	31	0.16	12	0.75	16	24	0.13	288	0.7
Kitchener	30/4/75	0.5	423	33	0.21	13	0.87	19	26	0.10	313	1.2
	3/6/75	0.4	372	30	0.13	11	0.69	23	25	0.13	276	1.1
	15/7/75	0.3	340	27	0.11	10	0.61	19	20	0.10	247	1.1
Iron	1/5/75	1.6	29	84	1.23	31	2.1	1.9	146	0.006	211	0.7
N. Toronto	2/5/75	1.6	29	86	1.40	31	2.0	2.6	153	0.001	221	0.7
	7/5/75	1.3	146	73	0.74	26	3.1	7.6	113	0.005	229	0.9
	10/6/75	1.3	24	71	0.72	25	1.6	1.6	114	0.003	209	0.7
	21/7/75	1.5	33	88	0.75	30	1.9	2.3	145	0.004	249	0.9

TABLE 18. Dates of Sludge Application and Harvest, Elora Bromegrass 1973 - 1975.

Operation		Year		
		1973	1974	1975
First application:	NH_4NO_3	May 9*	May 1	May 1
	Ca-sludge	May 11	April 26	May 1
	Al-sludge	May 14,24	May 2	May 2
	Fe-sludge	May 10	May 1	May 1
2nd application:	NH_4NO_3	- *	June 21	June 10
	Ca-sludge	June 22	June 20	June 11
	Al-sludge	June 25	June 21	June 10
	Fe-sludge	June 25	June 24	June 10
3rd application:	NH_4NO_3	- *	July 25	July 21
	Ca-sludge	July 30	July 26	July 18
	Al-sludge	July 31	July 26	July 18
	Fe-sludge	July 30	July 25	July 21
Harvests - 1st		June 14	June 17	June 6
2nd		July 25	July 22	July 17
3rd		Aug. 30	Aug. 26	Sept. 2

* In 1973 all of the ammonium nitrate for the season was applied in one application on May 9.

TABLE 19. Amounts of Various Constituents in the Sludges Applied to Elora Bromegrass Experiment in 1975 at 178 lb N/ac (200 kg N/ha).

	Ca sludge	Al sludge	Fe sludge
		lb/ac (kg/ha)	
Solids	8386 (9423)	3224 (3623)	3556 (3995)
Total N	178 (200)	178 (200)	178 (200)
Soluble & exch. NH_4-N	48 (54)	60 (67)	53 (60)
P_2O_5	187	285	396
P	(91)	(139)	(193)
K_2O	21	21	21
K	(20)	(20)	(20)
Ca	1054 (1184)	176 (198)	114 (128)
Mg	35 (39)	24 (27)	24 (27)
Na	36 (40)	30 (34)	14 (16)
Al	28 (32)	113 (127)	41 (46)
Fe	53 (60)	28 (31)	285 (320)
Mn	4.1 (4.6)	0.7 (0.8)	1.7 (1.9)
Cd	0.02 (0.03)	0.02 (0.03)	0.09 (0.10)
Cr	0.27 (0.30)	25 (28)	1.7 (1.9)
Cu	2.2 (2.5)	2.0 (2.2)	4.7 (5.3)
Ni	0.23 (0.26)	1.3 (1.5)	0.12 (0.13)
Pb	1.6 (1.8)	1.5 (1.7)	7.8 (8.8)
Zn	8 (9.0)	18 (20)	15 (13)
B	0.15 (0.17)	0.06 (0.07)	0.05 (0.06)
Hg	0.03 (0.03)	0.01 (0.01)	0.05 (0.06)
Mo	0.06 (0.07)	0.04 (0.05)	0.11 (0.12)
Se	0.012 (0.011)	0.007 (0.008)	<.0001 (<.0001)

TABLE 20. Total Amounts of Various Constituents in Sludges Applied to Elora Bromegrass Experiment Between 1973 and 1975 at the Rate of 178 lb N/ac (200 kg N/ha) Annually.

Constituents	Calcium Sludge		Aluminum Sludge		Iron Sludge	
	lb/ac	(kg/ha)	lb/ac	(kg/ha)	lb/ac	(kg/ha)
Solids	29,264	(32,807)	12,791	(14,340)	11,597	(13,002)
Total N	535	(600)	535	(600)	535	(600)
Soluble + Exch NH_4-N	134	(150)	193	(216)	173	(194)
P_2O_5	802		985		1233	
P		(391)		(480)		(601)
K_2O	56		48		56	
K		(52)		(45)		(52)
Ca	6,205	(6,957)	678	(760)	469	(526)
Mg	149	(167)	87	(97)	82	(92)
Na*	72	(80)	68	(76)	30	(34)
Al	90	(101)	632	(709)	176	(197)
Fe	206	(231)	101	(114)	593	(665)
Mn	12.1	(13.6)	2.1	(2.4)	4.9	(5.5)
Cd	0.11	(.13)	0.10	(.12)	0.24	(.27)
Cr	.88	(.99)	58.5	(65.6)	4.9	(5.6)
Cu	6.4	(7.2)	8.4	(9.4)	16.3	(18.3)
Ni	.66	(.74)	3.0	(3.4)	.44	(.50)
Pb	3.4	(3.8)	4.5	(5.1)	20.3	(22.8)
Zn	24.1	(27.0)	41.2	(46.2)	35.3	(39.6)
B*	.65	(.73)	.36	(.41)	.30	(.34)
Hg	.06	(.07)	.03	(.04)	.23	(.26)
Se†	.011	(.012)	.045	(.051)	<.0001	(.0001)
Mo†	.011	(.012)	.007	(.008)	.11	(.12)

* Na and B values based on 1974 and 1975 analyses.

† Mo and Se values based on 1975 analyses.

TABLE 21. Annual Dry Matter Yield of Bromegrass (three cuts). Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
	lb/ac (kg/ha)				
0 (0)	1497(1679)^{h*}				
89 (100)	4465(5005)^{fg}				
178 (200)	5591(6268)^{de}	3764(4220)^{g}	4974(5576)^{ef}	5007(5614)^{ef}	4582(5136)
356 (400)	6065(6799)^{cd}	5620(6301)^{de}	6675(7483)^{bc}	6441(7220)^{bc}	6245(7001)
712 (800)		7088(7947)^{ab}	7148(8013)^{ab}	6972(7816)^{ab}	7069(7925)
1424 (1600)		7544(8458)^{a}	6853(7683)^{ab}	7232(8108)^{ab}	7210(8083)
Average	4405(4938)	6004(6731)	6412(7189)	6413(7189)	6276(7036)

C.V. = 7.8%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability.

Level of significance of various effects by "F" test.	
Sources of sludge	N.S.
Rates of sludge	0.01
Sludge x rate interaction	0.05
Rates of ammonium nitrate	0.01

TABLE 22. Dry Matter Yield of Bromegrass, First Cut (June 6), Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			lb/ac (kg/ha)		
0 (0)	489 (548)^{e*}				
89 (100)	2377 (2665)^{d}				
178 (200)	2836 (3180)^{bcd}	1596 (1789)^{e}	2452 (2749)^{d}	2479 (2779)^{d}	2176 (2439)
356 (400)	3272 (3669)^{abc}	2599 (2914)^{cd}	3605 (4041)^{ab}	3336 (3740)^{abc}	3180 (3565)
712 (800)		3737 (4189)^{a}	3869 (4338)^{a}	3445 (3861)^{ab}	3683 (4129)
1424 (1600)		3800 (4260)^{a}	3586 (4020)^{ab}	3428 (3843)^{ab}	3604 (4041)
Average	2244 (2516)	2933 (3288)	3378 (3787)	3172 (3556)	3161 (3544)

C.V. = 14%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability.

Level of significance of various effects by "F" test	
Source of sludge	0.05
Rates of sludge	0.01
Sludge x rate interaction	N.S.
Rates of ammonium nitrate	0.01

TABLE 23. Dry Matter Yield of Bromegrass, Second Cut (July 17), Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				lb/ac (kg/ha)		
0	(0)	641 (719)^{h*}				
89	(100)	1143(1281)^{fg}				
178	(200)	1569(1759)^{cde}	1075(1205)^{g}	1492(1673)^{de}	1407(1577)^{ef}	1325(1485)
356	(400)	1543(1730)^{cde}	1660(1861)^{bcde}	1829(2051)^{bcd}	1852(2076)^{abc}	1780(1996)
712	(800)		1941(2176)^{ab}	1690(1895)^{bcde}	2167(2430)^{a}	1933(2167)
1424	(1600)		1677(1880)^{bcde}	1574(1765)^{cde}	1953(2189)^{ab}	1735(1945)
Average		1224(1372)	1588(1781)	1646(1846)	1845(2068)	1693(1898)

C.V. = 11.4%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability.

Level of significance of various effects by "F" test	
Sources of sludge	0.01
Rates of sludge	0.01
Sludge x rate interaction	0.05
Rates of ammonium nitrate	0.01

TABLE 24. Dry Matter Yield of Bromegrass, Third Cut (September 2), Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		lb/ac (kg/ha)				
0	(0)	368 (412)^{i*}				
89	(100)	945(1059)^{h}				
178	(200)	1186(1329)^{efgh}	1093(1225)^{fgh}	1029(1154)^{gh}	1122(1258)^{fgh}	1081(1212)
356	(400)	1249(1400)^{efg}	1361(1526)^{def}	1241(1391)^{efg}	1253(1404)^{efg}	1285(1440)
712	(800)		1411(1581)^{de}	1588(1780)^{cd}	1360(1524)^{def}	1453(1629)
1424	(1600)		2067(2317)^{a}	1693(1898)^{bc}	1852(2076)^{ab}	1871(2097)
Average		937(1050)	1483(1662)	1388(1556)	1397(1566)	1422(1595)

C.V. = 11.4%.

*Individual treatments not followed by a common letter are significantly different at 0.05 probability.

Level of significance of various effects by "F" test	
Sources of sludge	N.S.
Rates of sludge	0.01
Sludge x rate interaction	N.S.
Rates of ammonium nitrate	0.01

TABLE 25. Annual Dry Matter Yield of Bromegrass from Three Cuttings, Elora, 1974.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			dry matter - lb/ac (kg/ha)			
0	(0)	890 (990)^{a}*				
89	(100)	2750 (3080)^{bc}				
178	(200)	4120 (4620)^{cf}	2160 (2420)^{b}	3220 (3600)^{cd}	3060 (3430)^{cd}	2810 (3150)
356	(400)	6030 (6750)^{h}	3650 (4090)^{de}	4820 (5410)^{g}	4770 (5340)^{fg}	4410 (4950)
712	(800)		6340 (7100)^{h}	6060 (6790)^{h}	6240 (6990)^{h}	6210 (6960)
1424	(1600)		6990 (7840)^{i}	6150 (6896)^{h}	5960 (6680)^{h}	6370 (7140)
Average**			4790 (5360)	5060 (5680)	5010 (5610)	4950 (550)

*Individual treatment means not followed by a common letter are significantly different at 0.05 probability

Rates of sludge and the source-rate interaction are significantly different at 0.05 probability by "F" test.

TABLE 26. Nitrogen Concentration in First Cut (June 6), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				% N		
0	(0)	2.07^{ef*}				
89	(100)	1.78^{g}				
178	(200)	2.52^{e}	1.93^{efg}	2.18^{de}	1.93^{efg}	2.02
356	(400)	3.13^{a}	1.87^{fg}	2.43^{cd}	2.45^{c}	2.25
712	(800)		2.52^{e}	2.83^{b}	3.12^{a}	2.82
1424	(1600)		3.10^{a}	3.07^{ab}	3.18^{a}	3.12
Average		2.38	2.35	2.63	2.67	2.55

c.v. = 6.0%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources and rates of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.
Sludge x rate interaction significant at 0.01 probability level.

TABLE 27. Nitrogen Concentration in Second Cut (July 17), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				% N		
0	(0)	2.33 e*				
89	(100)	2.23 e				
178	(200)	2.83 d	2.38 e	2.30 e	2.42 e	2.37
356	(400)	3.72 ab	2.30 e	2.78 d	3.18 c	2.76
712	(800)		3.50 b	3.80 ab	3.53 ab	3.61
1424	(1600)		3.85 a	3.77 ab	3.62 ab	3.74
Average		2.78	3.01	3.16	3.19 ab	3.12

C.V. = 6.0%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range test.

Rates of sludge and ammonium nitrate are significantly different at 0.01 probability level by "F" test. Rate x sludge interaction significant at 0.01 probability. Sources of sludge are significantly different at 0.05 probability level.

TABLE 28. Nitrogen Concentration in Third Cut (September 2), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				% N		
0	(0)	2.90 de*				
89	(100)	2.82 e				
178	(200)	3.42 bc	3.05 cde	3.17 cde	3.25 cd	3.14
356	(400)	3.85 a	3.28 c	3.72 ab	3.73 ab	3.58
712	(800)		3.80 ab	3.77 ab	3.97 a	3.84
1424	(1600)		3.75 ab	3.92 a	4.03 a	3.90
Average		3.25	3.47	3.63	3.75	3.62

C.V. = 5.8%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources and rates of sludge, and rates of ammonium nitrate are significantly different at 0.01 probability level by "F" test.

TABLE 29. NO_3-N Concentration in First Cut (June 6), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source: Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				μg NO_3-N/g		
0	(0)	5^{c*}				
89	(100)	26^{c}				
178	(200)	76^{c}	5^{c}	10^{c}	6^{c}	7
356	(400)	1483^{b}	8^{c}	241^{c}	367^{c}	205
712	(800)		279^{c}	1383^{b}	1357^{b}	1006
1424	(1600)		1667^{b}	2267^{a}	2143^{a}	2026
Average		398	490	975	968	811

c.v. = 37%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.
Sludge x rate interaction significant at 0.05 probability level.

TABLE 30. NO_3-N Concentration in Second Cut (July 17), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			$\mu g\ NO_3$-N/g		
0 (0)	13 c*				
89 (100)	3 c				
178 (200)	66 c	8 c	7 c	12 c	9
356 (400)	1002 b	12 c	185 c	436 c	211
712 (800)		1165 b	1420 b	1320 b	1302
1424 (1600)		2118 a	2067 a	2083 a	2089
Average	271	826	920	963	903

C.V. = 35%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and ammonium nitrate are significantly different at 0.01 probability level by "F" test.

TABLE 31. NO_3-N Concentration in Third Cut (September 2), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			μg NO_3-N/g		
0 (0)	67^{e*}				
89 (100)	88^{e}				
178 (200)	743^{e}	393^{e}	497^{e}	550^{e}	480
356 (400)	2217^{c}	1007^{de}	2256^{c}	1893^{cd}	1717
712 (800)		2007^{cd}	3500^{ab}	2550^{bc}	2686
1424 (1600)		3950^{a}	3817^{a}	4050^{a}	3939
Average	779	1839	2516	2260	2205

c.v. = 33 %

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and ammonium nitrate are significantly different at 0.01 probability level by 'F' test. Sources of sludge are significantly different at 0.05 probability level.

TABLE 32. Phosphorus Concentration in First Cut (June 6), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				% P		
0	(0)	0.33^{abc*}				
89	(100)	0.25^{g}				
178	(200)	0.28^{efg}	0.34^{a}	0.34^{ab}	0.31^{abcde}	0.33
356	(400)	0.30^{bcdef}	0.32^{abcd}	0.29^{defg}	0.31^{abcde}	0.31
712	(800)		0.31^{abcde}	0.27^{fg}	0.30^{bcdef}	0.29
1424	(1600)		0.30^{cdef}	0.27^{fg}	0.33^{abc}	0.30
Average		0.29	0.32	0.29	0.31	0.31

c.v. = 6.7%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources and rates of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.
Sludge x rate interaction significant at 0.05 probability level.

TABLE 33. Phosphorus Concentration in Second Cut (July 17), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				% P		
0	(0)	0.36 bc*				
89	(100)	0.34 cde				
178	(200)	0.30 f	0.41 a	0.38 ab	0.38 ab	0.39
356	(400)	0.30 f	0.39 ab	0.32 cdef	0.34 cde	0.35
712	(800)		0.34 cd	0.31 def	0.31 def	0.32
1424	(1600)		0.35 cd	0.31 def	0.30 ef	0.32
Average		0.33	0.37	0.33	0.33	0.35

C.V. = 5.3%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by "F" test.

TABLE 34. Phosphorus Concentration in Third Cut (September 2), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			%P		
0 (0)	0.34 h*				
89 (100)	0.38 fgh				
178 (200)	0.37 gh	0.43 de	0.43 de	0.45 cd	0.44
356 (400)	0.40 efg	0.43 de	0.40 defg	0.42 def	0.42
712 (800)		0.44 de	0.38 fgh	0.49 be	0.43
1424 (1600)		0.51 b	0.39 efg	0.55 a	0.49
Average	0.37	0.45	0.40	0.48	0.44

C.V. = 5.9%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources and rates of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.

TABLE 35. Sodium Bicarbonate-extractable Phosphate in Surface Soil (0-6 in) Elora Grass, Fall, 1974.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	 Calcium Sludge	 Aluminium Sludge	 Iron Sludge	 Sludge Rate Average
0	(0)	10 ^{e*}		µg P/g		
89	(100)	8^{e}				
178	(200)	9^{e}	12 ^{e}	8 ^{e}	10 ^{e}	10
356	(400	7^{e}	27 ^{cd}	13 ^{e}	16 ^{de}	19
712	(800)		58 ^{b}	18 ^{de}	18 ^{de}	31
1424	(1600)		150 ^{a}	26 ^{cd}	32 ^{c}	69
Average		9	62	17	19	32

C.V. =26%

* Individual treatments followed by a common letter are not significantly different at the 0.05 probability level.

Source and rate of sludge and source-rate interaction significant at 0.01 probability level. ('F' Test).

TABLE 36. Sodium Bicarbonate-extractable Phosphate in Surface Soil (0-6 in) Elora Bromegrass Experiment. Fall, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			µg P/g		
0 (0)	17^{ef*}				
89 (100)	13^{f}				
178 (200)	13^{f}	45^{c}	16^{ef}	24^{def}	28
356 (400)	11^{f}	72^{b}	27^{def}	31^{cde}	43
712 (800)		127^{a}	31^{cde}	47^{c}	68
1424 (1600)		147^{a}	40^{cd}	62^{b}	82
Average	15	98	28	41	56

c.v. = 20 %

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge, rates of ammonium nitrate, and sludge x rate interaction are significantly different at 0.01 probability level by 'F' test.

TABLE 37. Potassium Concentration in Second Cut (July 17), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				% K		
0	(0)	2.70 a*				
89	(100)	2.53 abc				
178	(200)	2.01 de	2.63 ab	2.31 bcd	2.35 abcd	2.43
356	(400)	1.63 f	2.17 cde	2.19 cde	2.05 de	2.14
712	(800)		1.87 ef	2.19 cde	1.91 ef	1.99
1424	(1600)		2.11 de	2.69 a	2.51 abc	2.44
Average		2.22	2.19	2.35	2.20	2.25

C.V. = 8.5%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and ammonium nitrate are significantly different at 0.01 probability level by "F" test. Sludge x rate interaction significant at 0.01 probability level.

TABLE 38. Potassium Concentration in Third Cut (September 2), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			%K		
0 (0)	2.45 cd*				
89 (100)	2.64 bc				
178 (200)	2.45 cd	2.87 b	2.87 b	2.88 b	2.87
356 (400)	2.03 e	2.58 bc	2.73 bc	2.41 cd	2.57
712 (800)		1.92 e	2.90 b	2.58 bc	2.47
1424 (1600)		2.22 de	3.45 a	3.23 a	2.96
Average	2.39	2.40	2.99	2.78	2.72

C.V. = 6.9%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources and rates of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test. Sludge x rate interaction is significant at 0.01 probability level.

TABLE 39. Ammonium Acetate-extractable Potassium in Surface Soil (0-6 in), Elora, Bromegrass Plots, Fall, 1974.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			µg K/g		
0 (0)	101^{a*}				
89 (100)	89^{abc}				
178 (200)	85^{abc}	100^{a}	96^{ab}	96^{ab}	97
356 (400)	74^{c}	89^{abc}	85^{abc}	81^{bc}	85
712 (800)		84^{abc}	84^{abc}	88^{abc}	85
1424 (1600)		93^{ab}	84^{abc}	84^{abc}	87
Average	87	92	87	87	89

c.v. = 10 %

*Individual treatments not followed by a common letter are significantly different at 0.05 probability.

Rates of sludge and nitrate fertilizer are significantly different at 0.05 probability level by 'F' test.

TABLE 40. Ammonium Acetate-extractable Potassium in Surface Soil (0-6 in), Elora Bromegrass Experiment. Fall, 1975.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source			
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			μg K/g		
0 (0)	100^{a*}				
89 (100)	88^{b}				
178 (200)	77^{bc}	84^{bc}	80^{bc}	83^{bc}	82
356 (400)	75^{cd}	84^{bc}	79^{bc}	79^{bc}	80
712 (800)		72^{cd}	76^{bcd}	75^{cd}	74
1424 (1600)		64^{d}	79^{bc}	81^{bc}	75
Average	85	76	78	79	78

c.v. = 8.1 %

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.05 probability level by 'F' test. Rates of ammonium nitrate are significantly different at 0.01 probability level.

TABLE 41. pH of Surface Soil (0-6 in) Elora Grass, Fall, 1974.

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminium Sludge	Iron Sludge	Sludge Rate Average
0	(0)	7.43^{de*}				
89	(100)	7.50^{cde}				
178	(200)	7.33^{def}	7.60^{bcd}	7.50^{ede}	7.43^{de}	7.51
356	(400)	7.13^{fg}	7.73^{abc}	7.43^{de}	7.40^{de}	7.52
712	(800)		7.77^{ab}	7.40^{de}	7.30^{ef}	7.49
1424	(1600)		7.87^{a}	7.40^{de}	7.03^{g}	7.43
Average		7.35	7.74	7.43	7.29	7.49

C.V. = 1.9%

* Individual treatments followed by a common letter are not significantly different at the 0.05 probability level.

Source of sludge significant at the 0.01 level. Source-rate interaction significant at the 0.05 probability level. ('F' test)

TABLE 42. pH of Surface Soil (0-6 in) Elora Bromegrass Experiment, Fall 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
0	(0)	7.47^{bc*}				
89	(100)	7.53^{bc}				
178	(200)	7.47^{bc}	7.90^{a}	7.53^{bc}	7.47^{bc}	7.63
356	(400)	7.40^{c}	7.90^{a}	7.47^{bc}	7.40^{b}	7.59
712	(800)		7.97^{a}	7.53^{bc}	7.37^{b}	7.62
1424	(1600)		7.83^{a}	7.60^{b}	7.03^{b}	7.49
Average		7.47	7.90	7.53	7.32	7.58

c.v. = 1.1 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge, rates of ammonium nitrate and sludge × rate interaction are significantly different at 0.01 probability level by 'F' test.

TABLE 43. Ammonium Acetate-extractable Calcium in Surface Soil (0-6 in) Elora Bromegrass Experiment, Fall, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				mg Ca/g		
0	(0)	2.45^{d*}				
89	(100)	2.95^{d}				
178	(200)	2.35^{d}	3.63^{c}	2.73^{d}	2.60^{d}	2.99
356	(400)	2.77^{d}	3.78^{c}	2.72^{d}	2.73^{d}	3.08
712	(800)		5.13^{b}	2.77^{d}	2.50^{d}	3.47
1424	(1600)		6.00^{a}	2.82^{d}	2.28^{d}	3.70
Average		2.63	4.64	2.76	2.53	3.31

c.v. = 13 %

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge, rates of ammonium nitrate and sludge x rate interaction are significantly different at 0.01 probability level by 'F' test.

TABLE 44. Calcium Concentration in First Cut (June 6), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				% Ca		
0	(0)	0.47^{cdef*}				
89	(100)	0.44^{ef}				
178	(200)	0.51^{bcde}	0.44^{def}	0.45^{cdef}	0.41^{f}	0.44
356	(400)	0.53^{abcd}	0.47^{cde}	0.45^{cdef}	0.45^{cdef}	0.45
712	(800)		0.53^{abc}	0.47^{cdef}	0.58^{ab}	0.53
1424	(1600)		0.60^{a}	0.53^{abc}	0.58^{ab}	0.57
Average		0.49	0.51	0.48	0.50	0.50

c.v. = 9.6%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.01 probability level by 'F' test.

TABLE 45. Calcium Concentration in Second Cut (July 17), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			% Ca		
0 (0)	0.55 d*				
89 (100)	0.55 d				
178 (200)	0.57 cd	0.56 d	0.52 d	0.52 d	0.53
356 (400)	0.72 ab	0.50 d	0.57 cd	0.61 bcd	0.56
712 (800)		0.70 ab	0.72 ab	0.68 abc	0.70
1424 (1600)		0.79 a	0.70 ab	0.73 ab	0.74
Average	0.60	0.64	0.63	0.64	0.63

C.V. = 11%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and ammonium nitrate are significantly different at 0.01 probability level by "F" test.

TABLE 46. Ammonium Acetate-extractable Magnesium in Surface Soils (0-6 in) Elora Grass, Fall, 1974.

Nitrogen Rate		Nitrogen Source				
lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Rate Average
				µg Mg/g		
0	(0)	445^{abcd*}				
89	(100)	424^{cd}				
178	(200)	475^{abc}	400^{d}	445^{abcd}	443^{abcd}	429
356	(400)	475^{abc}	405^{d}	432^{bcd}	437^{abcd}	425
712	(800)		421^{cd}	413^{cd}	491^{ab}	442
1424	(1600)		411^{d}	427^{cd}	496^{a}	444
Average		455	409	429	467	435

CV = 7.1%

* Individual treatments followed by a common letter are not significantly different at the 0.05 probability level.

Sludge source and ammonium nitrate significant at the 0.01 and 0.05 probability levels respectively ("F" test).

TABLE 47. Magnesium Concentration in First Cut (June 6), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				% Mg		
0	(0)	0.18^{cde*}				
89	(100)	0.17^{cde}				
178	(200)	0.19^{cd}	0.15^{e}	0.17^{cde}	0.15^{e}	0.16
356	(400)	0.24^{a}	0.16^{de}	0.18^{cde}	0.17^{cde}	0.17
712	(800)		0.19^{cd}	0.18^{cde}	0.24^{a}	0.20
1424	(1600)		0.22^{ab}	0.20^{bc}	0.23^{a}	0.22
Average		0.20	0.18	0.18	0.20	0.19

c.v. = 8.2%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate and sludge are significantly different at 0.01 probability level by 'F' test. Sources of sludge significant at 0.05 probability. Sludge x rate interaction significant at 0.01 probability level.

TABLE 48. Magnesium Concentration in Second Cut (July 17), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			% Mg		
0 (0)	0.24 g*				
89 (100)	0.25 g				
178 (200)	0.32 de	0.24 g	0.26 fg	0.25 g	0.25
356 (400)	0.43 a	0.23 g	0.30 ef	0.33 cde	0.29
712 (800)		0.36 bcd	0.35 bcd	0.38 b	0.37
1424 (1600)		0.36 bcd	0.34 cde	0.34 cde	0.34
Average	0.31	0.30	0.31	0.32	0.31

C.V. = 7.3%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and ammonium nitrate are significantly different at 0.01 probability level by "F" test. Sources of sludge are significantly different at 0.05 probability level. Sludge x rate interaction is significant at 0.01 probability level.

TABLE 49. Magnesium Concentration in Third Cut (September 2), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		% Mg				
0	(0)	0.25 e*				
89	(100)	0.28 e				
178	(200)	0.34 cde	0.25 e	0.28 e	0.32 cde	0.29
356	(400)	0.47 a	0.29 e	0.33 cde	0.38 bcd	0.33
712	(800)		0.40 abc	0.32 cde	0.45 ab	0.39
1424	(1600)		0.31 de	0.34 cde	0.39 bcd	0.34
Average		0.34	0.31	0.32	0.39	0.38

C.V. = 13%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources and rates of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.

TABLE 50. Aluminum Concentration in Third Cut (September 2), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		µg Al/g				
0	(0)	92 a*				
89	(100)	55 bc				
178	(200)	59 bc	60 bc	67 b	63 b	63
356	(400)	32 cd	40 abc	51 abc	43 abc	44
712	(800)		41 abc	60 bc	56 bc	52
1424	(1600)		31 cd	26 d	24 d	27
Average		60	43	51	47	47

C.V. = 30%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and ammonium nitrate are significantly different at 0.01 probability level by 'F' test.

TABLE 51. Iron Concentration in First Cut (June 6), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				µg Fe/g		
0	(0)	50^{cde*}				
89	(100)	45^{de}				
178	(200)	51^{cde}	46^{cde}	46^{cde}	50^{cde}	47
356	(400)	77^{a}	42^{de}	46^{cde}	53^{cde}	47
712	(800)		57^{bcd}	60^{bc}	60^{bc}	59
1424	(1600)		57^{bcd}	56^{bcd}	67^{ab}	60
Average			51	52	57	53

c.v. = 13%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and ammonium nitrate are significantly different at 0.01 probability level by 'F' test.

TABLE 52. Iron Concentration in Third Cut (September 2), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				µg Fe/g		
0	(0)	156^{a}				
89	(100)	87^{bc}				
178	(200)	77^{c}	95^{bc}	83^{bc}	110^{b}	96
356	(400)	80^{c}	86^{bc}	88^{bc}	95^{bc}	90
712	(800)		83^{bc}	89^{bc}	96^{bc}	90
1424	(1600)		71^{c}	76^{c}	77^{c}	75
Average		100	84	84	95	88

c.v. = 15 %

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test. Rates of sludge are significantly different at 0.05 probability level.

TABLE 53. Manganese Concentration in First Cut (June 6), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				µg Mn/g		
0	(0)	44^{abc*}				
89	(100)	50^{ab}				
178	(200)	47^{abc}	45^{abc}	40^{abcd}	39^{abcd}	41
356	(400)	52^{a}	37^{bcd}	36^{cd}	37^{bcd}	36
712	(800)		35^{cd}	35^{cd}	40^{abcd}	37
1424	(1600)		29^{d}	36^{cd}	43^{abc}	36
Average		48	36	36	39	38

c.v. = 17%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

TABLE 54. Manganese Concentration in Second Cut (July 17), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			µg Mn/g		
0 (0)	71 a*				
89 (100)	61 bcd				
178 (200)	64 abc	47 gh	56 cdef	58 cde	54
356 (400)	69 abc	48 efgh	57 cde	57 cde	54
712 (800)		46 gh	54 defg	58 cd	53
1424 (1600)		42 h	54 defg	68 ab	55
Average	66	46	55	61	54

C.V. = 9.0%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate and sources of sludge are significantly different at 0.01 probability level by "F" test.

TABLE 55. Manganese Concentration in Third Cut (September 2), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			µg Mn/g		
0 (0)	86^{b*}				
89 (100)	71^{c}				
178 (200)	72^{c}	62^{cd}	60^{cd}	61^{cd}	61
356 (400)	100^{a}	53^{d}	62^{cd}	63^{cd}	59
712 (800)		52^{de}	60^{cd}	70^{c}	61
1424 (1600)		42^{e}	54^{d}	84^{b}	60
Average	82	52	59	69	60

c.v. = 9.4 %

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate, sources of sludge, and source X rate interaction are significantly different at 0.01 probability level by 'F' test.

TABLE 56. Cadmium Concentration in Second Cut (July 17), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		µg Cd/g				
0	(0)	0.17 b*				
89	(100)	0.20 b				
178	(200)	0.20 b	0.17 b	0.20 b	0.13 b	0.17
356	(400)	0.23 ab	0.17 b	0.20 b	0.20 b	0.19
712	(800)		0.23 ab	0.23 ab	0.23 ab	0.23
1424	(1600)		0.20 b	0.23 ab	0.33 a	0.25
Average		0.20	0.19	0.22	0.22	0.21

C.V. = 28%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.05 probability level by "F" test.

TABLE 57. Cadmium Concentration in Third Cut (September 2), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				µg Cd/g		
0	(0)	0.27^{cd} *				
89	(100)	0.27^{cd}				
178	(200)	0.21^{cd}	0.19^{d}	0.31^{bcd}	0.21^{cd}	0.24
356	(400)	0.23^{cd}	0.33^{bc}	0.23^{cd}	0.33^{bc}	0.27
712	(800)		0.27^{cd}	0.26^{cd}	0.41^{ab}	0.31
1424	(1600)		0.31^{bcd}	0.29^{bcd}	0.51^{a}	0.37
Average		0.25	0.25	0.27	0.37	0.30

c.v. = 23 %

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge are significantly different at 0.01 probability level by 'F' test. Sludge x rate interaction is significant at 0.05 probability level.

TABLE 58. Cadmium Concentration in Bromegrass Receiving Different Sources of Nitrogen, Elora, 1975.

	Source of nitrogen				
	None	NH_4NO_3	Ca sludge	Al sludge	Fe sludge
			µg/g		
First cut (June 6)	0.26	0.22	0.26	0.21	0.29
Second cut (July 17)	0.17	0.21	0.19	0.22	0.22
Third cut (Sept. 2)	0.27	0.24	0.25	0.27	0.37
Average	0.23	0.22	0.23	0.23	0.29

TABLE 59. Chromium Concentration in Second Cut (July 17), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	 Calcium Sludge	 Aluminum Sludge	 Iron Sludge	 Sludge Average
				µg Cr/g		
0	(0)	0.93^{a*}				
89	(100)	0.80^{abcd}				
178	(200)	0.43^{de}	0.50^{cde}	0.83^{abc}	0.57^{abcde}	0.63
356	(400)	0.57^{abcde}	0.50^{cde}	0.77^{abcd}	0.50^{cde}	0.59
712	(800)		0.30^{e}	0.53^{bcde}	0.77^{abcd}	0.53
1424	(1600)		0.50^{cde}	0.90^{ab}	0.60^{abcde}	0.67
Average		0.58	0.45	0.76	0.61	

c.v. = 32 %

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge are significantly different at 0.01 probability level by 'F' test. Rates of ammonium nitrate are significantly different at 0.05 probability level.

TABLE 60. Chromium Concentration in Bromegrass Receiving Different Sources of Nitrogen, Elora, 1975.

	Source of Nitrogen				
	None	NH_4NO_3	Ca sludge	Al sludge	Fe sludge
			μg/g		
First cut (June 6)	0.5	0.5	0.6	0.6	0.7
Second cut (July 17)	0.9	0.6	0.5	0.8	0.6
Third cut (Sept. 2)	1.2	1.0	1.0	2.9	1.0
Average	0.9	0.7	0.7	1.4	0.8

TABLE 61. Copper Concentration in First Cut (June 6), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	 Calcium Sludge	 Aluminum Sludge	 Iron Sludge	 Sludge Average
				µg Cu/g		
0	(0)	5.7^{h*}				
89	(100)	8.7^{defgh}				
178	(200)	9.0^{defg}	7.7^{efgh}	6.3^{gh}	7.7^{efgh}	7.2
356	(400)	11.3^{bcd}	7.0^{fgh}	10.3^{bcde}	10.3^{bcde}	9.2
712	(800)		9.7^{cdef}	13.0^{ab}	12.3^{abc}	11.7
1424	(1600)		13.3^{ab}	15.0^{a}	14.7^{a}	14.3
Average		8.7	9.4	11.2	11.2	10.6

c.v. = 17%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Rates of sludge and ammonium nitrate are significantly different at 0.01 probability level by 'F' test. Sources of sludge are significantly different at 0.05 probability level.

TABLE 62. Copper Concentration in Second Cut (July 17), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				µg Cu/g		
0	(0)	6.7 d*				
89	(100)	7.0 cd				
178	(200)	10.3 bc	7.3 cd	9.7 bcd	8.0 cd	8.3
356	(400)	13.7 a	9.0 bcd	9.3 bcd	11.7 ab	10.0
712	(800)		10.3 bc	15.0 a	14.0 a	13.1
1424	(1600)		14.7 a	15.0 a	15.0 a	14.9
Average		8.8	10.3	12.2	12.2	11.6

C.V. = 16%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and ammonium nitrate are significantly different at 0.01 probability level by "F" test. Sources of sludge are significantly different at 0.05 probability level.

TABLE 63. Copper Concentration in Third Cut (September 2), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		μg Cu/g				
0	(0)	12.7 d*				
89	(100)	15.0 cd				
178	(200)	25.3 a	16.0 bcd	16.3 bcd	20.3 abcd	17.6
356	(400)	18.7 abcd	18.0 abcd	22.0 abc	16.3 bcd	18.8
712	(800)		18.7 abcd	20.7 abcd	24.7 ab	21.3
1424	(1600)		19.0 abcd	19.3 abcd	19.3 abcd	19.2
Average		17.9	17.9	19.6	20.2	19.2

C.V. = 24%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.

TABLE 64. Nickel Concentration in Bromegrass Receiving Different Sources of Nitrogen, Elora, 1975.

	Source of nitrogen				
	None	NH_4NO_3	Ca Sludge	Al sludge	Fe sludge
			µg/g		
First cut (June 6)	1.0	1.6	1.7	1.7	1.6
Second cut (July 17)	0.9	1.6	1.3	1.4	1.4
Third cut (Sept. 2)	1.3	1.4	1.3	1.9	1.6
Average	1.1	1.5	1.4	1.7	1.5

TABLE 65. Nickel Concentration in Third Cut (September 2), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				µg/Ni/g		
0	(0)	1.3 bc*				
89	(100)	1.2 c				
178	(200)	1.4 bc	1.4 bc	1.2 c	1.1 c	1.2
356	(400)	1.5 bc	1.4 bc	2.3 a	1.4 bc	1.8
712	(800)		1.1 c	2.0 abc	1.7 abc	1.6
1424	(1600)		1.5 bc	2.2 abc	2.2 ab	2.0
Average		1.4	1.3	1.9	1.6	1.6

C.V. = 32%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge are significantly different at 0.05 probability level by 'F' test.

TABLE 66. Lead Concentration in Bromegrass Receiving Different Sources of Nitrogen, Elora, 1975.

		Source of nitrogen			
	None	NH_4NO_3	Ca-Sludge	Al-sludge	Fe sludge
			μg/g		
First cut (June 6)	2.0	1.9	1.6	1.9	1.8
Second cut (July 17)	2.0	1.8	1.4	1.5	1.4
Third cut (Sept. 2)	4.1	3.5	3.4	2.8	3.1
Average	2.7	2.4	2.1	2.1	2.1

TABLE 67. Zinc Concentration in First Cut (June 6), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				μg Zn/g		
0	(0)	16^{g*}				
89	(100)	17^{fg}				
178	(200)	19^{efg}	22^{def}	20^{efg}	22^{def}	21
356	(400)	30^{bc}	20^{efg}	23^{de}	24^{de}	22
712	(800)		26^{cd}	30^{bc}	32^{b}	29
1424	(1600)		30^{bc}	33^{b}	41^{a}	35
Average		21	24	26	30	27

c.v. = 12%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Rates and sources of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.

TABLE 68. Zinc Concentration in Second Cut (July 17), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			µg Zn/g			
0	(0)	32 ef*				
89	(100)	24 g				
178	(200)	34 ef	33 ef	29 fg	34 ef	32
356	(400)	36 def	37 cde	33 ef	38 bcde	36
712	(800)		36 def	42 bcd	44 bc	41
1424	(1600)		51 a	44 bc	44 bc	47
Average		32	40	37	40	39

C.V. = 10%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and ammonium nitrate are significantly different at 0.01 probability level by "F" test. Sludge x rate interaction is significant at 0.05 probability level.

TABLE 69. Zinc Concentration in Third Cut (September 2), Bromegrass, Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				µg Zn/g		
0	(0)	21^{h*}				
89	(100)	23^{gh}				
178	(200)	27^{fg}	27^{fg}	28^{fg}	29^{ef}	28
356	(400)	28^{ef}	30^{def}	34^{cd}	34^{cde}	33
712	(800)		36^{c}	36^{c}	46^{b}	39
1424	(1600)		49^{b}	35^{cd}	58^{a}	47
Average		25	35	33	42	37

c.v. = 9.0 %

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and ammonium nitrate, sources of sludge and sludge × rate interaction are significantly different at 0.01 probability level by 'F' test.

TABLE 70. Mercury, Molybdenum and Selenium Concentrations in Selected Treatments from Bromegrass Experiment, 1975.

Treatment	CUT			CUT			CUT		
	1	2	3	1	2	3	1	2	3
	Hg nanogram/g			Mo nanogram/g			Se nanogram/g		
Ammonium nitrate 100 kg N/ha	103	100	83	49	67	67	-	-	-
Ammonium nitrate 200 kg N/ha	-	-	-	-	-	-	40	50	60
Calcium sludge 1600 kg N/ha	-	-	-	-	-	-	40	30	40
Iron sludge 400 kg N/ha	110	77	93	39	44	86	-	-	-
Iron sludge 1600 kg N/ha	113	120	87	63	61	97	60	80	130

TABLE 71. Field Operations on Rate and Source of Sludge Experiments with Corn, 1975.

Treatment or description	Elora	Cambridge	Milton
Soil	Conestoga loam	Caledon loamy sand	Oneida clay loam
Plowed	April 28	April 23	November 27/74
Calcium sludge applied	May 2	May 9	No sludge applied.
Iron sludge applied	May 1	May 7	
Alum sludge applied	May 2	May 8	
Phosphate applied to ammonium nitrate plots and disked in before seeding			
	104 lb P_2O_5/ac (50 kg P/ha)	No phosphate required	No phosphate required.
Potassium applied to all treatments and disked in before seeding			
	97 lb K_2O/ac (90 kg K/ha)	43 lb K_2O/ac (40 kg K/ha)	No potassium required.
Seeding	May 22	May 22	May 13
(60 lb of 6-18-6 liquid fertilizer per acre banded with seed on all treatments)			
Emerged plants counted	May 29	May 29	--
Pre-thinning count	June 17	June 20	June 4
Thinning and sampling of seedlings	June 23	June 20	June 4
Silk and final stand counts	August 5	August 6	July 25
Final stand (plants/ac).	23,000	16,000	23,000
Plant height to flag leaf measurement	September 3	September 4	September 6
Grain harvested	October 2	October 10	October 6
Stover harvested	October 17	October 24	October 22
Plants lodged count	October 2	--	October 6

TABLE 72. Amounts of Various Constituents in Lime and Alum-treated Sludges Added in 1975 at 178 lb N/ac (200 kg N/ha) to Corn Experiments (Elora and Cambridge).

	Calcium Sludge		Aluminum Sludge	
	lb/ac	(kg/ha)	lb/ac	(kg/ha)
Solids	7757	(8716)	3051	(3428)
Total N	178	(200)	178	(200)
Soluble + Exch NH_4-N	62	(70)	70	(79)
P_2O_5	200		239	
P		(93)		(117)
K_2O	25		14.4	
K		(23.2)		(13.5)
Ca	1087	(1221)	123	(138)
Mg	33	(36.8)	21	(23.1)
Na	22	(25)	17	(19)
Al	29	(32.2)	113	(127)
Fe	59	(66.2)	24	(27.5)
Mn	4.5	(5.05)	0.69	(0.77)
Cd	0.02	(0.02)	0.02	(0.03)
Cr	0.24	(0.27)	23	(25.4)
Cu	1.59	(1.79)	1.7	(1.97)
Ni	0.34	(0.38)	0.96	(1.08)
Pb	1.31	(1.47)	1.4	(1.54)
Zn	8.1	(9.05)	16.5	(18.5)
B	0.06	(0.07)	0.04	(0.05)
Hg	0.023	(0.026)	0.011	(0.012)
Se	0.001	(0.001)	0.006	(0.007)
Mo	0.049	(0.055)	0.045	(0.050)

TABLE 73. Amounts of Various Constituents in Iron Sludge Added in 1975 at 178 lb N/ac (200 kg N/ha) to Elora and Cambridge Corn Experiments.

	Elora		Cambridge	
	lb/ac	(kg/ha)		
Solids	3851	(4327)	3878	(4357)
Total N	178	(200)	178	(200)
Soluble & Exch NH_4-N	59	(66)	71	(80)
P_2O_5	403		382	
P		(197)		(186)
K_2O	22		22	
K		(20)		(20)
Ca	107	(120)	95	(107)
Mg	24	(26.7)	22	(25.0)
Na	17	(19)	23	(23)
Al	43	(48)	61	(68)
Fe	310	(348)	265	(298)
Mn	1.9	(2.1)	1.7	(1.9)
Cd	0.10	(0.11)	0.09	(0.10)
Cr	1.7	(1.93)	9.3	(10.4)
Cu	5.0	(5.60)	4.6	(5.21)
Ni	0.12	(0.13)	0.48	(0.54)
Pb	8.6	(9.7)	7.2	(8.1)
Zn	13	(14.1)	15	(16.4)
B	0.04	(0.05)	0.05	(0.06)
Hg	0.07	(0.082)	0.05	(0.056)
Se	<.0001	(<.0001)	<.0001	(<.0001)
Mo	0.12	(0.14)	0.19	(0.31)

TABLE 74. Total Amounts of Various Nutrients and Metals Added to Elora Corn Experiment by Annual Application of Various Sludges at 178 lb N/ac (200 kg N/ha) from 1973 to 1975.

	Calcium sludge		Alum sludge		Iron sludge	
			lb/ac (kg/ha)			
Solids	29,104	(32,700)	12,204	(13,710)	11,704	(13,151)
Total N	534	(600)	534	(600)	534	(600)
Soluble & exch. NH_4-N	186	(209)	201	(226)	178	(200)
P_2O_5	695		994		1237	
P		(339)		(485)		(604)
K_2O	79		44		59	
K		(74)		(42)		(55)
Ca	6,154	(6915)	508	(571)	445	(500)
Mg	159	(179)	86	(97)	78	(88)
Na	48	(54)	47	(53)	35	(39)
Al	114	(128)	450	(506)	123	(138)
Fe	234	(263)	60	(67)	733	(824)
Mn	12	(13)	2.1	(2.4)	5.0	(5.6)
Cd	0.07	(.08)	0.09	(.10)	0.27	(0.3)
Cr	0.87	(.98)	52	(58)	4.7	(5.3)
Cu	5.0	(5.6)	8.1	(9.1)	16	(18)
Ni	0.84	(.94)	2.5	(2.8)	0.36	(.40)
Pb	3.7	(4.2)	3.8	(4.3)	21	(24)
Zn	24	(27)	34	(38)	34	(38)
B	0.26	(.29)	0.11	(.12)	0.28	(.31)
Hg	0.05	(.06)	0.04	(.04)	0.23	(.26)
Mo*	0.15	(.17)	0.14	(.16)	0.36	(.40)
Se*	0.003	(.003)	0.018	(.02)	0.001	(.001)

* based on amounts applied in 1975.

TABLE 75. Total Amounts of Various Nutrients and Metals Added to Cambridge Corn Experiment by Annual Application of Various Sludges at 178 lb N/ac (200 kg N/ha) from 1973 to 1975.

	Calcium sludge		Alum sludge		Iron sludge	
			lb/ac	(kg/ha)		
Solids	36,800	(41,350)	13,286	(14,928)	11,920	(13,393)
Total N	534	(600)	534	(600)	534	(600)
Soluble & exch. NH_4-N	135	(152)	191	(215)	183	(206)
P_2O_5	814		984		1272	
P		(398)		(481)		(621)
K_2O	61		37		50	
K		(57)		(35)		(47)
Ca	8,178	(9190)	689	(774)	409	(460)
Mg	132	(148)	97	(109)	82	(92)
Na	49	(55)	48	(54)	39	(44)
Al	98	(110)	1234	(1387)	145	(163)
Fe	198	(222)	133	(149)	729	(819)
Mn	13	(15)	2.3	(2.6)	5.2	(5.8)
Cd	0.15	(.17)	0.14	(.16)	0.24	(.26)
Cr	1.7	(1.9)	64	(72)	12	(13)
Cu	6.5	(7.3)	8.3	(9.3)	16	(18)
Ni	1.0	(1.1)	3.2	(3.6)	0.8	(.9)
Pb	4.7	(5.3)	4.6	(5.2)	19	(21)
Zn	27	(30)	41	(46)	37	(42)
B	0.26	(.29)	0.30	(.34)	0.17	(.19)
Hg	0.06	(.07)	0.04	(.04)	0.19	(.21)
Mo*	0.15	(.17)	0.14	(.16)	0.57	(.64)
Se*	0.003	(.003)	0.018	(.02)	<0.001	(<.001)

* based on amounts applied in 1975.

TABLE 76. Total Amounts of Various Nutrients and Metals in Sludges Applied in 1973 and 1974 at the Rate of 178 lb N/ac (200 kg N/ha) at Milton.

Constituent	Calcium Sludge		Aluminum Sludge		Iron Sludge	
	lb/ac	kg/ha	lb/ac	kg/ha	lb/ac	kg/ha
Total N	356	400	356	400	356	400
Soluble N	72	81	116	130	109	122
Exch. N	6	6.7	8.6	9.6	10	11
Solids	12733	14261	11807	13224	8347	9348
P_2O_5	531		879		879	
P		259		431		440
K_2O	27		29		29	
K		24		27		27
Ca	4883	5469	582	652	363	407
Mg	88	99	83	93	60	67
Na*	32	36	26	29	18	20
Al	47	53	1699	1903	75	84
Fe	99	111	111	124	393	440
Cd	.09	0.10	.10	.11	.17	.19
Cr	.99	1.11	39	44	2.8	3.1
Cu	3.9	4.4	6.1	6.8	10.3	11.5
Hg	.03	.03	.04	.05	.18	.20
Mn	6.6	7.4	1.7	1.9	3.12	3.49
Ni	.45	.50	2.1	2.4	.28	.31
Pb	2.6	2.9	3.1	3.5	11.2	12.5
Zn	14	16	24	27	20	22
B*	.24	.27	.24	.27	.12	.13

*Sodium and Boron not determined in 1973. Values presented are based on 1974 analysis.

TABLE 77. Emergence of Corn Seedlings at Cambridge Experiment.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
	Plants Emerged per Experimental Plot				
0 (0)	52 abc*				
89 (100)	47 abcde				
178 (200)	45 bcde	53 abc	53 abc	56 ab	54
356 (400)	42 cde	58 a	47 abcde	55 ab	53
712 (800)		57 a	49 abcd	49 abcd	52
1424 (1600)		58 a	35 e	40 de	44
Average**	47	57	46	50	51

C.V. = 3.7%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

** Sludge sources are significantly different at 0.01 probability level by "F" test.
Rates of sludge and of ammonium nitrate are significantly different at 0.05 probability level by "F" test.

TABLE 78. Effect of Different Sources of Nitrogen on Dry Weight of Corn Seedling Shoots (6-7 leaf stage). Cambridge Corn Experiment. Sampled June 20, 1975.

	Source of Nitrogen				
	No Nitrogen	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge
Dry Weight/ Seedling (g)*	1.16	1.41	1.55	1.28	1.45

* Sludge sources are significantly different at 0.05 probability level by "F" test.

TABLE 79. Dry Weight of Corn Seedling Shoots, Elora Experiment (6-8 leaf stage). Sampled June 23, 1975.

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Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		g/seedling			
0 (0)	2.56 a *				
89 (100)	1.76 de				
178 (200)	1.88 cd	1.43 e	2.08 bcd	2.18 abc	1.90
356 (400)	1.86 cd	1.85 cd	2.06 bcd	2.10 bcd	2.00
712 (800)		1.91 cd	1.75 de	2.17 abc	1.95
1424 (1600)		2.35 ab	1.71 de	2.51 a	2.19
Average	2.02	1.88	1.90	2.24	2.01

C.V. = 10.6%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by "F" test. Rates of sludge are significantly different at 0.05 probability level. Sludge x rate interaction is significant at 0.01 probability level.

TABLE 80. Corn Grain Yield (15% moisture) Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				lb/ac (kg/ha)		
0	(0)	6364 (7134)^{bc*}				
89	(100)	6840 (7668)^{abc}				
178	(200)	6365 (7136)^{bc}	6242 (6998)^{c}	7163 (8030)^{a}	6790 (7612)^{abc}	6731 (7546)
356	(400)	6733 (7548)^{abc}	6476 (7260)^{abc}	6901 (7736)^{abc}	6801 (7624)^{abc}	6726 (7540)
712	(800)		6238 (6993)^{c}	6317 (7082)^{c}	7124 (7987)^{a}	6560 (7354)
1424	(1600)		6806 (7630)^{abc}	6806 (7630)^{abc}	7095 (7954)^{ab}	6902 (7738)
Average		6576 (7372)	6440 (7220)	6796 (7619)	6952 (7794)	6730 (7545)

c.v. = 5.7 %

* Individual treatment not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge are significantly different at 0.01 probability level by 'F' test.

TABLE 81. Corn Grain Yield (15% moisture) Cambridge, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		lb/ac (kg/ha)				
0	(0)	3237 (3629)^{ab*}				
89	(100)	3341 (3746)^{ab}				
178	(200)	3347 (3752)^{ab}	3981 (4463)^{a}	2673 (2997)^{b}	3152 (3534)^{ab}	3269 (3665)
356	(400)	2987 (3349)^{ab}	3062 (3433)^{ab}	2456 (2753)^{b}	3209 (3598)^{ab}	2909 (3261)
712	(800)		2807 (3147)^{b}	2666 (2989)^{b}	3053 (3423)^{ab}	2842 (3187)
1424	(1600)		2615 (2932)^{b}	2750 (3083)^{b}	3056 (3426)^{ab}	2807 (3147)
Average		3228 (3619)	3117 (3494)	2637 (2956)	3118 (3495)	2957 (3315)

c.v. = 18%

* Individual treatment not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

TABLE 82. Corn Grain Yield (15% moisture) Milton, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			lb/ac (kg/ha)		
0 (0)	4963 (5564)^{bcd*}				
89 (100)	4191 (4698)^{e}				
178 (200)	4635 (5196)^{de}	5386 (6038)^{bcd}	4976 (5578)^{bcd}	5231 (5864)^{bcd}	5198 (5827)
356 (400)	4728 (5301)^{cde}	5312 (5955)^{bcd}	5448 (6108)^{abc}	5158 (5783)^{bcd}	5307 (5949)
712 (800)		5488 (6153)^{abc}	5089 (5705)^{bcd}	5208 (5839)^{bcd}	5262 (5899)
1424 (1600)		6124 (6865)^{a}	5291 (5932)^{bcd}	5641 (6324)^{ab}	5686 (6374)
Average	4629 (5190)	5578 (6253)	5201 (5831)	5310 (5953)	5363 (6012)

c.v. = 7.5%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate are significantly different at 0.01 probability level.

TABLE 83. Corn Grain Yield at Elora, Cambridge and Milton, 1973 to 1975.

		Nitrogen Source			
Year	No Nitrogen	Ammonium Nitrate	Calcium Sludge	Aluminium Sludge	Iron Sludge
			lb/ac (kg/ha)		
Elora					
1973	3722	5189	5181	5091	5360
	(4169)	(5812)	(5803)	(5702)	(6003)
1974	4368	6058	6247	6442	6455
	(4892)	(6785)	(6997)	(7215)	(7230)
1975	6364	6646	6440	6796	6952
	(6840)	(7444)	(7220)	(7619)	(7794)
Average	4728	5959	5952	6106	6252
	(5300)	(6680)	(6673)	(6845)	(7009)
Cambridge					
1973	3464	2865	2845	3013*	2763
	(3880)	(3208)	(3186)	(3374)	(3095)
1974	3453	3682	3592	3566	3785
	(3868)	(4123)	(4023)	(3994)	(4239)
1975	3237	3225	3117	2637	3118
	(3629)	(3612)	(3494)	(2956)	(3495)
Average	3383	3254	3182	3070	3220
	(3792)	(3648)	(3568)	(3441)	(3610)
Milton					
1973	3308	3404	4242	3699*	4292
	(3705)	(3812)	(4751)	(4143)	(4807)
1974	1411	1645	2636	1979	2594
	(1580)	(1842)	(2952)	(2216)	(2905)
1975	4963	4518	5578	5201	5310
	(5564)	(5060)	(6253)	(5831)	(5953)
Average	3226	3186	4150	3624	4063
	(3616)	(3571)	(4652)	(4063)	(4555)

*The highest rate of application of sludge was omitted.

TABLE 84. Corn Stover Yield at Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source			
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		dry matter	lb/ac (kg/ha)		
0 (0)	2542 (2850)^{bc*}				
89 (100)	3053 (3423)^{abc}				
178 (200)	2747 (3080)^{abc}	3499 (3923)^{a}	3574 (4007)^{a}	3062 (3433)^{abc}	3379 (3788)
356 (400)	2955 (3313)^{abc}	3057 (3427)^{abc}	3006 (3370)^{abc}	2968 (3327)^{abc}	3010 (3374)
712 (800)		2353 (2637)^{c}	3024 (3390)^{abc}	3057 (3427)^{abc}	2811 (3151)
1424 (1600)		3099 (3373)^{abc}	3262 (3657)^{ab}	2634 (2953)^{bc}	2969 (3328)
Average	2825 (3167)	2979 (3340)	3217 (3606)	2930 (3285)	3042 (3410)

c.v. = 14%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

TABLE 85. Corn Stover Yield at Cambridge, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		Dry matter lb/ac (kg/ha)				
0	(0)	1543 (1730)^{b*}				
89	(100)	2105 (2360)^{ab}				
178	(200)	1947 (2183)^{ab}	1829 (2050)^{ab}	2625 (2943)^{a}	1840 (2063)^{ab}	2098 (2352)
356	(400)	2474 (2773)^{ab}	2331 (2613)^{ab}	2602 (2917)^{a}	2482 (2783)^{ab}	2472 (2771)
712	(800)		2441 (2737)^{ab}	2099 (2353)^{ab}	1927 (2160)^{ab}	2156 (2417)
1424	(1600)		2830 (3173)^{a}	2402 (2693)^{ab}	2420 (2713)^{ab}	2551 (2860)
Average		2017 (2262)	2358 (2643)	2432 (2727)	2168 (2430)	2319 (2600)

c.v. = 24%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

TABLE 86. Corn Stover Yield at Milton, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		dry matter	lb/ac (kg/ha)			
0	(0)	2854 (3200)*				
89	(100)	2988 (3350)				
178	(200)	2569 (2880)	2738 (3070)	2605 (2920)	2551 (2860)	2631 (2950)
356	(400)	2533 (2840)	2480 (2780)	2658 (2980)	2498 (2800)	2542 (2850)
712	(800)		2524 (2830)	2640 (2960)	2462 (2760)	2542 (2850)
1424	(1600)		2551 (2860)	2614 (2930)	2845 (3190)	2667 (2990)
Average		2736 (3070)	2578 (2890)	2631 (2950)	2587 (2900)	2596 (2910)

c.v. = 12%

* Individual treatments are not significantly different at 0.05 probability level by Duncan's Multiple Range Test.

TABLE 87. Number of Plants Lodged in Experimental Plot, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
0	(0)	5^{c} *				
89	(100)	16^{ab}				
178	(200)	18^{a}	23^{a}	8^{bc}	21^{a}	17
356	(400)	19^{a}	18^{a}	16^{ab}	19^{a}	17
712	(800)		26^{a}	19^{a}	24^{a}	23
1424	(1600)		23^{a}	22^{a}	25^{a}	24
Average		15	23	16	22	20

c.v. = 29%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources and rates of sludge are significantly different at 0.05 probability level by 'F' test. Rates of ammonium nitrate are significantly different at 0.01 probability level.

TABLE 88. Effect of Different Sources of Nitrogen on Concentration of Major Nutrients in Corn Seedlings. Elora Experiment. Sampled June 23, 1975. (6-8 leaf stage).

	Source of Nitrogen				
	No Nitrogen	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge
% N*	4.10	3.81	4.08	3.85	3.88
% P**	0.35	0.33	0.37	0.33	0.34
% K**	3.10	3.31	3.34	3.88	3.65
% Ca**	0.78	0.80	0.90	0.75	0.82

* Sludge sources are significantly different at 0.05 probability level by "F" test.

** Sludge sources are significantly different at 0.01 probability level by "F" test.

TABLE 89. Nitrogen Concentration in Corn Seedling Shoots. Cambridge Experiment Sampled June 20, 1975. (6-7 leaf stage).

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge** Average
			% N		
0 (0)	4.10 a *				
89 (100)	4.12 a				
178 (200)	4.08 ab	3.78 b	4.03 ab	3.93 ab	3.92
356 (400)	4.02 ab	4.00 ab	4.22 a	4.08 ab	4.10
712 (800)		4.05 ab	4.12 a	4.25 a	4.14
1424 (1600)		4.03 ab	4.18 a	4.18 a	4.13
Average**	4.08	3.97	4.14	4.11	4.07

C.V. = 4.0%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Source and rates of sludge are significantly different at 0.05 probability level by "F" test.

TABLE 90. Nitrogen Concentration in Corn Stover, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				% N		
0	(0)	0.75^{b} *				
89	(100)	0.92^{ab}				
178	(200)	1.05^{a}	0.88^{ab}	0.93^{ab}	0.90^{ab}	0.91
356	(400)	1.03^{a}	1.02^{a}	1.02^{a}	1.13^{a}	1.06
712	(800)		1.03^{a}	1.07^{a}	1.05^{a}	1.05
1424	(1600)		1.00^{a}	1.08^{a}	1.08^{a}	1.06
Average		0.94	0.98	1.03	1.04	1.02

c.v. = 13%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate are significantly different at 0.05 probability level by 'F' test.

TABLE 91. Nitrogen Concentration in Corn Stover. Milton, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source: Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		% N				
0	(0)	0.72 ef *				
89	(100)	0.73 ef				
178	(200)	0.80 def	0.98 abcd	0.63 f	0.87 bcdef	0.84
356	(400)	1.10 ab	0.85 cdef	0.80 def	0.95 bcde	0.87
712	(800)		1.08 abc	0.92 bcde	1.05 abc	1.02
1424	(1600)		0.98 abcd	1.20 a	0.93 bcde	1.04
Average		0.84	0.98	0.90	0.95	0.94

c.v. = 13.2

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and ammonium nitrate are significantly different at 0.01 probability level. Sludge x rate interaction is significant at 0.05 probability level.

TABLE 92. Nitrogen Concentration in Corn Grain. Milton, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source: Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				%N		
0	(0)	1.63^{de} *				
89	(100)	1.67^{de}				
178	(200)	1.72^{bcd}	1.82^{ab}	1.55^{e}	1.80^{abc}	1.72
356	(400)	1.87^{a}	1.75^{abcd}	1.78^{abc}	1.75^{abcd}	1.76
712	(800)		1.77^{abcd}	1.82^{ab}	1.82^{ab}	1.80
1424	(1600)		1.78^{abc}	1.77^{abcd}	1.85^{ab}	1.80
Average		1.73	1.78	1.73	1.80	1.77

c.v. = 4.0%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge are significantly different at 0.05 probability level by 'F' test. Rates of ammonium nitrate are significantly different at 0.01 probability level.
Sludge x rate interaction is significant at 0.01 probability level.

TABLE 93. NO_3-N Concentration in Corn Stover Harvested October 17, 1975, from Elora Corn Experiment.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			μg NO_3-N/g		
0 (0)	94^{f*}				
89 (100)	406^{ef}				
178 (200)	642^{cde}	592^{cdef}	748^{cde}	499^{def}	613
356 (400)	835^{bcde}	498^{def}	1057^{abc}	647^{cde}	734
712 (800)		937^{abcde}	592^{cdef}	997^{abcd}	842
1424 (1600)		740^{cde}	1323^{ab}	1450^{a}	1171
Average	494	692	930	898	840

c.v. = 37 %

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and ammonium nitrate are significantly different at 0.01 probability level by 'F' test. Sludge X rate interaction significant at 0.05 probability level.

TABLE 94. NO_3-N Concentration in Corn Stover Harvested October 24, 1975, from Cambridge Corn Experiment.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			μg NO_3-N/g		
0 (0)	4700^{ab*}				
89 (100)	3463^{ab}				
178 (200)	4885^{ab}	1668^{b}	3667^{ab}	3517^{ab}	2951
356 (400)	6308^{ab}	4333^{ab}	6467^{ab}	4408^{ab}	5069
712 (800)		7850^{a}	6130^{ab}	3600^{ab}	5860
1424 (1600)		3317^{ab}	5970^{ab}	7117^{a}	5469
Average	4839	4292	5558	4660	4837

c.v. = 54 %

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

TABLE 95. NO_3-N Concentration in Corn Stover Harvested October 22, 1975, from Milton Corn Experiment.

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				$\mu g\ NO_3$-N/g		
0	(0)	134^{d*}				
89	(100)	179^{d}				
178	(200)	234^{d}	862^{cd}	189^{d}	1080^{cd}	710
356	(400)	4085^{a}	769^{cd}	649^{cd}	644^{cd}	688
712	(800)		3050^{ab}	1280^{bcd}	1660^{bcd}	1997
1424	(1600)		1393^{bcd}	1407^{bcd}	2098^{bc}	1633
Average		1158	1519	881	1371	1257

c.v. = 77 %

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.05 probability level by 'F' test. Rates of ammonium nitrate are significantly different at 0.01 probability level.

TABLE 96. Sodium Bicarbonate-extractable Phosphate in Surface Soil (0-6 in) Elora Corn Experiment. Fall, 1974.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source: Ammonium Nitrate	Calcium Sludge	Aluminium Sludge	Iron Sludge	Sludge Rate Average
				µg P/g		
0	(0)	13 cde*				
89	(100)	11 de				
178	(200)	8 e	33 bcde	17 bcde	14 cde	21
356	(400)	11 de	29 bcde	27 bcde	26 bcde	27
712	(800)		75 a	36 bcd	38 bc	50
1424	(1600)		83 a	40 b	69 a	64
Average		11	55	30	37	41

C.V. = 40%

* Individual treatments followed by a common letter are not significantly different at the 0.05 probability level.

Source and rate of sludge significant at 0.01 probability level ('F' Test).

TABLE 97. Sodium Bicarbonate-extractable Phosphate in Surface Soil (0-6 in) Elora Corn Experiment. Fall, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			μg P/g		
0 (0)	20^{fg*}				
89 (100)	28^{fg}				
178 (200)	14^{g}	56^{cde}	31^{fg}	27^{fg}	38
356 (400)	24^{fg}	66^{bcd}	45^{def}	40^{efg}	50
712 (800)		117^{a}	60^{bcde}	73^{bc}	83
1424 (1600)		147^{a}	76^{bc}	84^{b}	102
Average	22	96	53	56	69

c.v. = 24 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test. Sludge × rate interaction is significant at 0.05 probability level.

TABLE 98. Sodium Bicarbonate-extractable Phosphate in Surface Soil (0-6 in) Cambridge Corn Experiment. Fall, 1974.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminium Sludge	Iron Sludge	Sludge Rate Average.
				µg P/g		
0	(0)	79^{def*}				
89	(100)	70^{ef}				
178	(200)	69^{f}	90^{cdef}	77^{def}	82^{def}	83
356	(400	80^{def}	113^{bc}	95^{cdef}	75^{def}	94
712	(800)		127^{ab}	100^{bcde}	103^{bcd}	110
1424	(1600)		143^{a}	80^{def}	112^{bc}	112
Average		75	118	88	93	100

C.V. = 16%

* Individual treatments followed by a common letter are not significantly different at the 0.05 probability level

Source and rate of sludge significant at the 0.01 probability level.

Source x rate interaction significant at 0.05 probability level. ('F' Test)

TABLE 99. Sodium Bicarbonate-extractable Phosphate in Surface Soil (0-6 in) Cambridge, Corn Experiment. Fall, 1975.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				µg P/g		
0	(0)	80^{b*}				
89	(100)	66^{b}				
178	(200)	65^{b}	114^{b}	83^{b}	72^{b}	90
356	(400)	76^{b}	133^{b}	88^{b}	78^{b}	100
712	(800)		227^{a}	101^{b}	93^{b}	140
1424	(1600)		340^{a}	92^{b}	150^{b}	194
Average		72	204	91	89	131

c.v. = 39 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.

TABLE 100. Sodium Bicarbonate-extractable Phosphate in Surface Soils (0-6 in) Corn, Milton, Fall, 1974.

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminium Sludge	Iron Sludge	Sludge Rate Average
				Nitrogen Source		
			µg P/g			
0	(0)	33^{gh*}				
89	(100)	46^{fgh}				
178	(200)	57^{defg}	66^{def}	47^{efgh}	52^{defgh}	55
356	(400)	32^{h}	83^{c}	52^{defgh}	52^{defgh}	64
712	(800)		112^{b}	49^{defgh}	70^{cde}	77
1424	(1600)		140^{a}	54^{defgh}	71^{cd}	82
Average		42	101	50	61	71

C.V. = 19%

* Individual treatments followed by a common letter are not significantly different at the 0.05 probability level.

Source and rate of sludge, ammonium nitrate, and sludge-rate interaction significant at the 0.01 probability level ('F' test).

TABLE 101. Phosphorus Concentration in Corn Seedling Shoots, Elora Experiment. Sampled June 23, 1975 (6-8 leaf stage).

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		%P			
0 (0)	0.35^{abcd*}				
89 (100)	0.33^{bcd}				
178 (200)	0.32^{cd}	0.38^{a}	0.31^{cd}	0.31^{d}	0.34
356 (400)	0.34^{abcd}	0.38^{a}	0.32^{cd}	0.33^{bcd}	0.34
712 (800)		0.37^{ab}	0.33^{bcd}	0.34^{abcd}	0.35
1424 (1600)		0.37^{ab}	0.34^{abcd}	0.36^{abc}	0.36
Average	0.34	0.37	0.33	0.34	0.35

C.V. = 6.7%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.01 probability level by "F" test.

TABLE 102. Phosphorus Concentration in Corn Seedling Shoots. Cambridge Experiment Sampled June 20, 1975 (6-7 leaf stage).

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			% P		
0 (0)	0.36 abc*				
89 (100)	0.35 abcd				
178 (200)	0.32 bcd	0.30 d	0.32 bcd	0.31 cd	0.31
356 (400)	0.30 d	0.35 abcd	0.34 abcd	0.33 abcd	0.34
712 (800)		0.35 abcd	0.35 abcd	0.35 abcd	0.35
1424 (1600)		0.36 ab	0.34 abcd	0.37 a	0.36
Average	0.33	0.34	0.34	0.34	0.34

C.V. = 7.5%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sludge rates are significantly different at 0.01 probability level by "F" test.
Ammonium nitrate rates are significantly different at 0.05 probability level by "F" test.

TABLE 103. Ammonium Acetate-extractable Potassium in Surface Soil (0-6 in) Elora Corn, Fall, 1974.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source: Ammonium Nitrate	Calcium Sludge	Aluminium Sludge	Iron Sludge	Sludge Rate Average
			µg K/g			
0	(0)	104 ^{abc*}				
89	(100)	97 ^{bc}				
178	(200)	101 ^{abc}	101 ^{abc}	99 ^{bc}	93 ^{c}	98
356	(400)	104 ^{abc}	105 ^{abc}	100 ^{bc}	103 ^{abc}	103
712	(800)		109 ^{ab}	100 ^{bc}	101 ^{abc}	104
1424	(1600		111 ^{ab}	101 ^{abc}	115 ^{a}	109
Average		102	107	100	103	103

C.V. = 7%

* Individual treatments followed by a common letter are not significantly different at the 0.05 probability level.

Rate of sludge significant at 5% probabilty level ("F" Test).

TABLE 104. Ammonium Acetate-extractable Potassium in Surface Soil (0-6 in) Elora Corn Experiment. Fall, 1975.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source			
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			μg K/g		
0 (0)	87^{d*}				
89 (100)	88^{cd}				
178 (200)	87^{d}	91^{bcd}	84^{d}	85^{d}	87
356 (400)	89^{bcd}	92^{abcd}	93^{abcd}	93^{abcd}	93
712 (800)		93^{abcd}	87^{d}	96^{abcd}	92
1424 (1600)		100^{abc}	104^{a}	101^{ab}	102
Average	88	94	92	94	93

c.v. = 7.2 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.05 probability level by 'F' test.

TABLE 105. Ammonium Acetate-extractable Potassium and Magnesium in Surface Soil (0-6 in) Receiving Different Sources of Nitrogen. Corn Experiment. Cambridge, Fall, 1974.

	K	Mg
	µg/g	
Ammonium nitrate	108	170
Ca sludge	111	138
Al sludge	112	143
Fe sludge	112	156

TABLE 106. Ammonium Acetate-extractable Potassium in Surface Soil (0-6 in) Receiving Different Sources of Nitrogen. Corn Experiment, Milton, Fall, 1974.

	K µg/g
Ammonium nitrate	189
Ca sludge	168
Al sludge	195
Fe sludge	182

TABLE 107. Potassium Concentration in Corn Stover, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source: Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		% K				
0	(0)	1.02 b*				
89	(100)	0.92 b				
178	(200)	0.83 b	0.83 b	1.16 ab	1.05 b	1.01
356	(400)	0.99 b	0.84 b	0.86 b	0.95 b	0.88
712	(800)		0.90 b	0.81 b	1.14 ab	0.95
1424	(1600)		0.93 b	1.21 ab	1.54 a	1.23
Average		0.94	0.87	1.01	1.17	1.02

c.v. = 22%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge are significantly different at 0.01 probability level by 'F' test.

Rates of sludge are significantly different at 0.05 probability level.

TABLE 108. Potassium Concentration in Corn Seedlings Samples from Milton Plots, June 4, 1975. (6 leaf stage).

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				% K		
0	(0)	4.02 abcd*				
89	(100)	4.55 ab				
178	(200)	4.45 abcd	4.19 abcd	4.21 abcd	4.43 abcd	4.28
356	(400)	4.64 a	3.90 bcd	4.27 abcd	4.17 abcd	4.11
712	(800)		3.76 d	4.12 abcd	4.59 ab	4.16
1424	(1600)		3.79 cd	4.53 ab	4.47 abc	4.26
Average		4.42	3.91	4.28	4.42	4.20

C.V. = 8.5

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

** Sludge sources are significantly different at 0.01 probability level by "F" test.

TABLE 109. pH of Surface Soil (0-6 in) Elora Corn, Fall, 1974.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminium Sludge	Iron Sludge	Sludge Rate Average
0	(0)	7.43 b*				
89	(100)	7.53 b				
178	(200)	7.40 b	7.83 a	7.33 b	7.33 b	7.50
356	(400)	7.37 b	7.80 a	7.37 b	7.33 b	7.50
712	(800)		7.83 a	7.33 b	7.13 c	7.43
1424	(1600		7.77 a	7.13 c	6.87 c	7.26
Average		7.43	7.81	7.29	7.17	7.42

C.V. = 1.4%

* Individual treatments followed by a common letter are not significantly different at the 0.05 probability level.

Source and rate of sludge significant at the 0.01 probability level. Source -rate interaction significant at 0.05 probability level ('F' test).

TABLE 110. pH of Surface Soil (0-6 in) Elora Corn Experiment. Fall, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
0 (0)	7.47 e*				
89 (100)	7.83 ab				
178 (200)	7.50 c	7.97 a	7.53 c	7.60 bc	7.70
356 (400)	7.57 c	7.93 a	7.53 c	7.33 cd	7.60
712 (800)		8.07 a	7.53 c	7.33 cd	7.64
1424 (1600)		7.97 a	7.47 c	7.10 cd	7.51
Average	7.59	7.98	7.52	7.34	7.61

C.V. = 1.9%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge are significantly different at 0.01 probability level by "F" test. Rates of ammonium nitrate are significantly different at 0.05 probability level.

TABLE 111. pH of Surface Soil (0-6 in) Cambridge Corn, Fall, 1974.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminium Sludge	Iron Sludge	Sludge Rate Average
0	(0)	7.40 b*				
89	(100)	7.30 b				
178	(200)	7.27 bc	7.80 a	7.37 b	7.33 b	7.50
356	(400)	7.27 bc	7.70 a	7.30 b	7.27 bc	7.42
712	(800)		7.83 a	7.27 bc	7.40 b	7.50
1424	(1600)		7.73 a	7.33 b	7.07 c	7.38
Average		7.31	7.77	7.32	7.26	7.45

C.V. = 1.6%

* Individual treatments followed by a common letter are not significantly different at the 0.05 probability level.

Source of sludge significant at the 0.01 probability level ('F' test)

TABLE 112. pH of Surface Soil (0-6 in) Corn, Cambridge, Fall, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
0 (0)	7.53^{b*}				
89 (100)	7.30^{bc}				
178 (200)	7.40^{b}	7.97^{a}	7.50^{b}	7.43^{b}	7.63
356 (400)	7.43^{b}	7.83^{a}	7.40^{b}	7.37^{b}	7.53
712 (800)		7.90^{a}	7.43^{b}	7.40^{b}	7.58
1424 (1600)		7.97^{a}	7.43^{b}	7.13^{c}	7.51
Average	7.42	7.92	7.44^{b}	7.33	7.56

c.v. = 1.8 %

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.

TABLE 113. pH of Surface Soil (0-6 in) Corn, Milton, Fall, 1974.

Nitrogen Rate		Nitrogen Source				
lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Rate Average
0	(0)	6.33 ^{c*}				
89	(100)	6.40 ^{c}				
178	(200)	6.20 ^{c}	7.07 ^{b}	6.47 ^{c}	6.50^{c}	6.68
356	(400)	5.67 ^{d}	7.47 ^{ab}	6.40 ^{c}	6.20 ^{c}	6.69
712	(800)		7.47 ^{ab}	6.30 ^{c}	6.37 ^{c}	6.71
1424	(1600)		7.63 ^{a}	6.27 ^{c}	6.20 ^{c}	6.70
Average **		6.15	7.41	6.36	6.32	6.69

C.V. = 4.3%

* Individual treatments followed by a common letter are not significantly different at the 0.05 probability level.

Sludge source and ammonium nitrate significant at the 0.01 probability level ('F' test)

TABLE 114. Ammonium Acetate-extractable Calcium in Surface Soil (0-6 in) Elora Corn Experiment. Fall, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source: Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			mg Ca/g		
0 (0)	2.37^{c*}				
89 (100)	2.93^{c}				
178 (200)	2.30^{c}	4.33^{b}	2.40^{c}	2.57^{c}	3.10
356 (400)	2.87^{c}	4.53^{b}	2.83^{c}	2.62^{c}	3.33
712 (800)		5.87^{a}	2.97^{c}	2.80^{c}	3.88
1424 (1600)		5.83^{a}	2.75^{c}	2.45^{c}	3.61
Average	2.62	5.09	2.74	2.61	3.48

c.v. = 14 %

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test. CAP

Rates and sources of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.

TABLE 115. Ammonium Acetate-extractable Calcium in Surface Soil (0-6 in) Cambridge Corn Experiment. Fall, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			mg Ca/g		
0 (0)	2.08^{de*}				
89 (100)	1.78^{e}				
178 (200)	1.58^{a}	2.67^{cd}	2.05^{de}	1.77^{e}	2.16
356 (400)	1.97^{de}	3.25^{c}	2.03^{de}	1.70^{e}	2.33
712 (800)		4.53^{b}	2.07^{de}	2.18^{de}	2.93
1424 (1600)		5.33^{a}	2.03^{de}	1.87^{de}	3.08
Average	1.85	3.95	2.05	1.88	2.62

c.v. = 17 %

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates and source of sludges, rates of ammonium nitrate and sludge x rate interaction are significantly different at 0.01 probability level by 'F' test.

TABLE 116. Calcium Concentration in Corn Seedlings Sampled from Milton Plots, June 4, 1975, (6 leaf stage).

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			% Ca		
0 (0)	0.72 c*				
89 (100)	0.74 c				
178 (200)	0.77 c	0.96 ab	0.74 c	0.76 c	0.82
356 (400)	0.75 c	0.83 abc	0.71 c	0.76 c	0.77
712 (800)		1.00 a	0.97 ab	0.69 c	0.89
1424 (1600)		1.01 a	0.79 bc	0.75 c	0.85
Average	0.75	0.95	0.80	0.74	0.83

C.V. = 12.7%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge are significantly different at the 0.01 probability level by "F" test.

TABLE 117. Calcium Concentration in Corn Stover. Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				% Ca		
0	(0)	0.38^{ab*}				
89	(100)	0.31^{ab}				
178	(200)	0.33^{ab}	0.30^{b}	0.40^{ab}	0.37^{ab}	0.35
356	(400)	0.44^{ab}	0.32^{ab}	0.41^{ab}	0.34^{ab}	0.36
712	(800)		0.35^{ab}	0.48^{a}	0.41^{ab}	0.41
1424	(1600)		0.45^{ab}	0.47^{ab}	0.47^{ab}	0.46
Average		0.37	0.36	0.44	0.40	0.40

c.v. = 22%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.05 probability level by 'F' test.

TABLE 118. Ammonium Acetate-extractable Magnesium in Surface Soil (0-6 in) Elora Corn, Fall, 1974.

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminium Sludge	Iron Sludge	Sludge Rate Average
			Nitrogen Source			
			µg Mg/g			
0	(0)	485 abc*				
89	(100)	469 abc				
178	(200)	565 a	387 c	539 ab	445 bc	457
356	(400)	533 ab	445 bc	477 abc	528 ab	484
712	(800)		408 c	459 bc	533 ab	467
1424	(1600)		413 c	456 bc	570 a	480
Average		513	413	483	519	472

C.V. = 11%

* Individual treatments followed by a common letter are not significantly different at the 0.05 probability level.

Source of sludge significant at the 0.01 probability level by "F" test.

TABLE 119. Ammonium Acetate-extractable Magnesium in Surface Soil (0-6 in) Milton, Corn, Fall, 1974.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source			
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			µg Mg/g		
0 (0)	249^{a*}				
89 (100)	221^{a}				
178 (200)	248^{a}	146^{b}	247^{a}	229^{a}	207
356 (400)	241^{a}	132^{b}	264^{a}	255^{a}	217
712 (800)		136^{b}	221^{a}	223^{a}	193
1424 (1600)		149^{b}	259^{a}	261^{a}	223
Average	240	141	248	242	210

c.v. = 12 %

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.

TABLE 120. Magnesium Concentration in Corn Seedling Shoots. Elora Experiment Sampled June 23, 1975 (6-8 leaf stage).

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
	% Mg				
0 (0)	0.44 a *				
89 (100)	0.39 abcd				
178 (200)	0.43 abc	0.38 abcd	0.38 abcd	0.40 ab	0.39
356 (400)	0.37 bcd	0.44 a	0.37 cd	0.35 cd	0.39
712 (800)		0.34 cd	0.33 d	0.35 cd	0.34
1424 (1600)		0.36 cd	0.33 d	0.33 d	0.34
Average	0.41	0.38	0.35	0.36	0.37

C.V. = 9.3%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and ammonium nitrate are significantly different at 0.01 probability level by "F" test.

TABLE 121. Magnesium Concentration in Corn Stover. Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		% Mg			
0 (0)	0.30 bc*				
89 (100)	0.29 bc				
178 (200)	0.36 a	0.31 bc	0.28 c	0.29 bc	0.30
356 (400)	0.34 ab	0.33 abc	0.30 bc	0.33 abc	0.32
712 (800)		0.31 bc	0.32 abc	0.30 bc	0.31
1424 (1600)		0.31 bc	0.32 abc	0.29 bc	0.31
Average	0.33	0.32	0.31	0.30	0.31

C.V. = 9.2%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate are significantly different at 0.01 probability level by "F" test.

TABLE 122. Aluminum Concentration in Corn Grain. Elora, 1974.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	 Calcium Sludge	 Aluminum Sludge	 Iron Sludge	 Sludge Average
		Al - µg/g				
0	(0)	2.3^{c*}				
89	(100)	2.6^{c}				
178	(200)	2.5^{c}	2.0^{c}	2.6^{c}	2.4^{c}	2.3
356	(400)	2.8^{ab}	2.2^{c}	2.3^{c}	4.5^{a}	3.0
712	(800)		2.0^{c}	1.9^{c}	3.1^{ab}	2.3
1424	(1600)		2.8^{ab}	2.4^{c}	2.7^{ab}	2.6
Average		2.6	2.2	2.3	3.2	2.6

c.v. = 39%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge are significantly different at 0.05 probability level by 'F' test.

TABLE 123. Aluminum Concentration in Corn Stover. Milton, 1975.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			µg Al/g			
0	(0)	450 abc*				
89	(100)	350 ab				
178	(200)	480 ab	340 ab	480 ab	390 abc	410
356	(400)	109 c	300 ab	280 ab	700 a	430
712	(800)		490 ab	340 ab	390 abc	410
1424	(1600)		490 ab	300 ab	230 ab	340
Average		347	410	350	430	400

C.V. = 46%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate are significantly different at 0.05 probability level by 'F' test. Sludge x rate interaction is significant at 0.05 probability level.

TABLE 124. Manganese Concentration in Corn Grain, Milton, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				µg Mn/g		
0	(0)	6.3^{abcd*}				
89	(100)	6.7^{abcd}				
178	(200)	7.0^{abc}	7.0^{abc}	7.0^{abc}	4.7^{cd}	6.2
356	(400)	8.0^{a}	5.3^{cd}	7.0^{abc}	6.3^{abcd}	6.2
712	(800)		5.7^{bcd}	7.7^{ab}	5.7^{bcd}	6.3
1424	(1600)		6.0^{abcd}	6.7^{abcd}	7.7^{ab}	6.8
Average		7.0	6.0	7.1	6.1	6.4

c.v. = 16%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge, and the source-rate interaction are significantly different at 0.05 probability level by 'F' test.

TABLE 125. Cadmium Concentration in Corn Stover, Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			Cd µg/g			
0	(0)	0.32 cd*				
89	(100)	0.24 d				
178	(200)	0.32 cd	0.32cd	0.35 cd	0.29 cd	0.32
356	(400)	0.43 cd	0.24 d	0.40 cd	0.51 bc	0.38
712	(800)		0.24 d	0.32 cd	0.47 bcd	0.34
1424	(1600)		0.43 cd	0.67 ab	0.80 a	0.63
Average		0.33	0.31	0.43	0.52	0.42

C.V. = 29%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources and rates of sludge are significantly different at 0.01 probability level by 'F' test.

TABLE 126. Chromium Concentration in Corn Stover, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		Cr - µg/g				
0	(0)	1.33 abcd*				
89	(100)	0.83 bcde				
178	(200)	0.73 bcde	0.63e	0.83 bcde	0.70 cde	0.72
356	(400)	1.07 bcde	0.67 de	1.37 abc	0.87 bcde	0.97
712	(800)		0.57 e	1.40 ab	1.07 bcde	1.01
1424	(1600)		0.70 cde	1.83 a	1.10 bcde	1.21
Average		0.99	0.64	1.36	0.93	0.98

C.V. = 35%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources and rates of sludge are significantly different at 0.01 and 0.05 probability levels by "F" test respectively.

TABLE 127. Copper Concentration in Corn Stover, Milton, 1975.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			µg Cu/g			
0	(0)	5.6 f *				
89	(100)	5.9 f				
178	(200)	6.0 ef	7.2 abcdef	7.1 bcdef	7.1 bcdef	7.1
356	(400)	8.3 abcd	6.4 def	6.5 def	7.2 abcdef	6.7
712	(800)		7.9 abcde	8.9 ab	8.7 abc	8.5
1424	(1600)		9.1 a	8.8 ab	6.8 cdef	8.2
Average		6.4	7.6	7.8	7.4	7.6

C.V. = 13%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and ammonium nitrate are significantly different at 0.01 probability level by "F" test.

TABLE 128. Lead Concentration in Corn Stover, Elora, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
	Pb- μg/g				
0 (0)	3.6 abc*				
89 (100)	3.2 abc				
178 (200)	2.5 bc	2.8 bc	3.2 abc	4.7 ab	3.6
356 (400)	3.3 abc	3.6 abc	3.2 abc	4.0 abc	3.6
712 (800)		2.4 c	2.4 c	5.1 a	3.3
1424 (1600)		3.3 abc	3.6 abc	4.4 abc	3.8
Average	3.2	3.0	3.1	4.5	3.6

C.V. = 32%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge are significantly different at 0.01 probability level by 'F' test.

TABLE 129. Zinc Concentration in Corn Stover, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		Zn - µg/g				
0	(0)	23 e*				
89	(100)	18 e				
178	(200)	20 e	40 cde	37 cde	35 cde	37
356	(400)	23 e	29 de	39 cde	59 bc	43
712	(800)		60 bc	50 bcd	72 b	60
1424	(1600)		55 bc	72 b	106 a	78
Average		21	46	49	68	55

C.V. = 28%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources and rates of sludge and rate of ammonium nitrate are significantly different at 0.01 probability level by 'F' test.

Sludge x rate interaction is significant at 0.05 probability level.

TABLE 130. Zinc Concentration in Corn Grain, Elora, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		Zn - µg/g				
0	(0)	19^{cde*}				
89	(100)	23^{bcde}				
178	(200)	17^{e}	22^{bcde}	19^{de}	24^{abcde}	22
356	(400)	21^{bcde}	22^{bcde}	22^{bcde}	21^{bcde}	22
712	(800)		26^{abcd}	24^{abcde}	28^{ab}	26
1424	(1600)		26^{abcd}	31^{a}	27^{abc}	28
Average		20	24	24	25	24

c.v. = 17%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.01 probability level by 'F' test. Rates of ammonium nitrate are significantly different at 0.05 probability level.

TABLE 131. Zinc Concentration in Corn Grain, Cambridge, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				Zn - µg/g		
0	(0)	29^{ab*}				
89	(100)	29^{ab}				
178	(200)	32^{ab}	29^{ab}	26^{b}	35^{ab}	30
356	(400)	30^{ab}	31^{ab}	28^{ab}	33^{ab}	31
712	(800)		33^{ab}	28^{ab}	35^{ab}	32
1424	(1600)		38^{ab}	40^{a}	40^{a}	39
Average		30	33	31	36	33

c.v. = 19%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.01 probability level by 'F' test.

TABLE 132. Zinc Concentration in Corn Grain, Milton, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				Zn- µg/g		
0	(0)	25^{abc*}				
89	(100)	26^{abc}				
178	(200)	26^{abc}	25^{bc}	33^{a}	19^{c}	25
356	(400)	29^{ab}	20^{c}	29^{ab}	26^{abc}	25
712	(800)		25^{bc}	29^{ab}	25^{bc}	26
1424	(1600)		24^{bc}	29^{ab}	30^{ab}	28
Average		27	23	30	25	26

c.v. = 15%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge are significantly different at 0.01 probability level, and sludge x rate interaction is significant at 0.05 probability level by 'F' test.

TABLE 133. Zinc Concentration in Corn Stover, Milton, 1975.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source: Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
				Zn - µg/g		
0	(0)	$17.0^{\text{bcdef}*}$				
89	(100)	15.0^{cdef}				
178	(200)	18.0^{bcde}	12.3^{ef}	17.0^{bcdef}	14.3^{def}	14.6
356	(400)	18.0^{bcde}	12.0^{ef}	18.0^{bcde}	20.0^{bcd}	16.7
712	(800)		11.0^{f}	18.7^{bcd}	21.3^{bc}	17.0
1424	(1600)		21.0^{bc}	30.7^{a}	22.7^{b}	24.8
Average		17.0	14.1	21.1	19.6	18.3

c.v. = 18%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge are significantly different at 0.01 probability level by 'F' test.

TABLE 134. Molybdenum Concentration in Stover and Grain of Corn Receiving Highest Rate of Sludge, at Elora, Cambridge and Milton, 1975.

Treatment	ELORA		CAMBRIDGE		MILTON	
	Grain	Stover	Grain	Stover	Grain	Stover
	µg/g					
NH_4NO_3, 100 kg N/ha	0.14	0.75	0.32	0.78	0.12	0.17
Ca sludge, 1600 kg N/ha	0.24	0.82	0.58	1.7	0.22	0.30
Al sludge, 1600 kg N/ha	0.21	0.93	0.32	1.1	0.14	0.22
Fe sludge, 1600 kg N/ha	0.20	0.85	0.43	0.90	0.22	0.13

TABLE 135. Mercury Concentration in Stover and Grain of Corn Receiving Highest Rate of Sludge at Elora, Cambridge and Milton, 1975.

	ELORA		CAMBRIDGE		MILTON	
Treatment	Grain	Stover	Grain	Stover	Grain	Stover
			Hg - nanogram/g			
NH_4NO_3, 100 kg N/ha	8.8	23.8	5.6	15.9	4.8	12.7
Ca sludge, 1600 kg N/ha	9.4	23.8	5.8	18.3	6.2	13.7
Al sludge, 1600 kg N/ha	6.7	24.2	7.2	16.0	10.7	12.9
Fe sludge, 1600 kg N/ha	7.4	31.3	7.2	19.2	8.3	15.8

TABLE 136. Selenium Concentration in Stover and Grain of Corn Receiving Highest Rate of Sludge at Elora, Cambridge and Milton, 1975.

	ELORA		CAMBRIDGE		MILTON	
Treatment	Grain	Stover	Grain	Stover	Grain	Stover
			µg/g			
NH_4NO_3, 100 kg N/ha	0.02	0.06	0.03	0.08	0.02	0.07
Ca sludge, 1600 kg N/ha	0.01	0.06	0.03	0.07	0.03	0.07
Fe sludge, 1600 kg N/ha	0.02	0.07	0.05	0.07	0.04	0.05

TABLE 137. Concentration of Cadmium, Copper, Nickel, Lead and Zinc in Subsurface Soil Solution Sampled in Fall, 1975, from Elora Corn Experimental Plots.

Treatment	October 23/November 6th					November 20/December 4th				
	Cd	Cu	Ni	Pb	Zn	Cd	Cu	Ni	Pb	Zn
			µg/1					µg/1		
A. 90 cm depth										
Ammonium Nitrate, 100 kg N/ha	2.8 (2)*	18 (2)	8 (2)	31 (1)	**	1.9 (3)	31 (3)	51 (3)	41 (3)	60 (1)
Iron Sludge, 200 kg N/ha	0.8 (2)	15 (2)	11 (2)	23 (1)	23 (1)	1.2 (2)	33 (2)	25 (2)	47 (2)	43 (2)
Iron Sludge, 400 kg N/ha	3.0 (2)	16 (2)	13 (1)	48 (2)	**	2.1 (1)	20 (2)	14 (2)	14 (2)	**
Iron Sludge, 800 kg N/ha	1.2 (2)	14 (2)	16 (2)	22 (2)	**	2.3 (2)	32 (2)	23 (2)	47 (2)	58 (2)
Ammonium Nitrate, 400 kg N/ha	2.3 (3)	18 (3)	21 (3)	45 (2)	**	1.6 (2)	17 (3)	13 (3)	28 (1)	**
B. 45 cm depth										
Ammonium Nitrate, 100 kg N/ha	5.0 (2)	13 (3)	12 (3)	32 (3)	**	0.7 (3)	15 (3)	16 (2)	20 (2)	69 (2)
Calcium Sludge, 1600 kg N/ha	1.3 (2)	18 (3)	10 (2)	25 (2)	**	1.0 (3)	38 (3)	10 (3)	15 (2)	79 (1)
Aluminum Sludge, 1600 kg N/ha	0.8 (3)	19 (3)	15 (3)	25 (2)	**	1.3 (1)	20 (2)	10 (2)	19 (1)	**
Iron Sludge, 1600 kg N/ha	0.2 (1)	18 (2)	14 (2)	25 (1)	13 (1)	1.7 (3)	16 (3)	18 (3)	21 (3)	68 (2)

* Numbers in parenthesis indicate number of samples representing the mean value.

** Not detected.

† Composited of samples obtained on dates shown.

5. NITROGEN

5.1 Objectives

The objectives of this part of the study are to determine factors involved in the conversion of sludge nitrogen in the soil to NH_4^+ and NO_3^-, the volatilization of NH_3 from sludge applied in the field and to determine the movement of NO_3^- through the soil profile.

5.2 Field Studies of Conversion and Movement of Sludge Nitrogen in Soil

5.2.1 Materials and methods

5.2.1.1 Soil profile sampling for NO_3^-, NH_4^+ and pH. Three replicates of soil in plots receiving 0, 356 (400) and 712 (800) lb N/ac (kg/ha) of Fe-treated sludge were sampled in each of the three continuing corn experiments and in the grass experiment in April or May, June, September and November, 1975. However, soil samples were taken only in May, June and September from the corn experiment on clay loam in Milton. Although sludge was not applied to the Milton trial in 1975, it was thought desirable to determine the residual effects of sludge applications from the previous two years. The following depths or layers were sampled: 0-6 (0-15), 6-12 (15-30), 12-18 (30-45), 18-24 (45-60), and 24-36 (60-90) in (cm). Nitrate (NO_3^-), exchangeable ammonium (NH_4^+) and pH determinations were made following methods reported in the 1973 report (Volume II).

5.2.1.2 Surface soil sampling for NO_3^-, NH_4^+ and pH. Near the end of June, the surface 0-6 in (0-15 cm) soil of plots receiving ammonium nitrate at 89 (100) and 356 (400) lb N/ac (kg N/ha) and Ca- and Al-treated sludges at 356 (400) and 712 (800) lb N/ac (kg N/ha) were sampled from the three corn experiments. Data from similar treatments with the Fe sludge from the 0-6 in (0-15 cm) layer of the profile sampling were included for comparisons. Nitrate (NO_3^-), exchangeable ammonium (NH_4^+) and pH were determined following the methods reported in the 1973 report (Volume II).

5.2.1.3 Subsoil solution sampling. Soil solution samplers were placed at the 45 or 90 cm depth in selected plots which received 200, 400, 800 and 1600 kg N/ha as Fe sludge, 1600 kg N/ha as Al or Ca sludge, and 100 and 400 kg N/ha as NH_4NO_3 fertilizer on the corn experiment at the Elora Research Station. Three replicates of each treatment were sampled.

Samplers were also placed at the 90 cm depth in plots of the runoff experiment at the Elora research station which received 120 kg N/ha as NH_4NO_3 or 800 kg N/ha sludge applied in the spring. Two samplers were placed in each of these plots in both replications on the 2% slope. Soil solution samples were obtained on April 14, 16 and 22, 1975, from samplers which were placed in the soil profile the previous summer. Samples were also taken on Oct. 23, Nov. 6 and 20, and Dec. 4, 1975, with samplers placed in the soil profile during the summer of 1975. Both NO_3^- and Cl^- analyses were done on the collected samples.

5.2.2 Results and discussion

5.2.2.1 Soil profile sampling for NO_3^-, NH_4^+ and pH.

NO_3^- concentration in soil profiles: The data in Tables 139 and 140 show that there was considerable residual NO_3^- in the first sampling (April or May) from the previous sludge applications. The amount of NO_3^- in the sandy loam profile on April 22 (Table 138) was apparently not related to the previous sludge application. This may have been due to greater leaching losses occurring as well as insufficient time for mineralization and nitrification of the organic N present to increase the NO_3^- content. Although there was a small but significant increase in NO_3^- content from previous sludge applications in the bromegrass experiment on April 23 (Table 141) there was considerably less NO_3^- present than under the adjacent corn plots on silt loam (Table 139).

By the end of June, the content of NO_3^- in the profiles of the corn experiments on sandy loam (Table 138) and silt loam (Table 139) had increased substantially whereas the NO_3^- content in soil from the bromegrass plots showed much smaller increases (Table 141). This was likely due to the fact that only one-third of the sludge had been applied to the plots before this sampling was done. It was evident that there was a considerable quantity of NO_3^- present in the 15 to 90 cm depth in the clay loam soil where sludge was applied the previous two years (Table 140).

However, most of this NO_3^- may have been that present at the previous sampling on May 12.

In September, after plant uptake of N had almost ceased, there were substantial quantities of NO_3^- remaining in the soil profile of the sandy loam (Table 138) and silt loam (Table 139) where sludge was applied. During the period from September to November leaching apparently removed more than one-half of the NO_3^- from the sandy loam profile (Table 138). Although there was some movement of NO_3^- down the silt loam profile (Table 139) from September until November, leaching was not as pronounced as in the sandy loam profile. There was little evidence of leaching in the clay loam profile (Table 140). Actually, it appeared as though there was some disappearance of NO_3^- possibly through denitrification.

There was some apparent movement of NO_3^- in the silt loam profile under bromegrass from September to November (Table 141). However, absorption of NO_3^- by the bromegrass crop may have also occurred during this period.

NH_4^+ concentration in soil profile: There was evidence of residual NH_4^+ present in the 0-15 cm layer from previous sludge applications in all profiles except the silt loam profile at the first sampling in April (Tables 142, 143, 144, 145). The NH_4^+-N concentration in the 0-15 cm layer of the silt loam profile increased slightly by the June sampling from sludge applications. In general, the quantity of NH_4^+ was not greatly affected by the sludge applications probably reflecting the rapid nitrification of NH_4^+ to NO_3^-.

pH in soil profiles: In general, the soil pH increased significantly with depth in all the soil profiles as a result of natural soil profile forming factors (Tables 146, 147, 148, 149). Sludge applications generally had small, if any, effect on soil pH. Small decreases in pH occurred with the June and November samplings of both the sandy loam and silt loam profiles under corn with sludge applications (Tables 146 and 147). Also, a small decrease with sludge applications was evident with the April sampling on the silt loam under corn (Table 147).

5.2.2.2 Surface soil sampling for NO_3^-, NH_4^+ and pH.

NO_3^--N concentration in surface soils: Increasing both ammonium nitrate and sludge rates resulted in significant increases in the NO_3^--N concentration of the 0-15 cm layer of the sandy loam and silt loam soils (Tables 150 and 151). The 400 kg N/ha rate as ammonium nitrate generally resulted in a much higher concentration of NO_3^- than the same rate of sludge N indicating the lower availability of sludge N. There did not appear to be any significant differences among the sludges with respect to NO_3^- production at each level of sludge application.

There was evidence of NO_3^--N production from sludge applied the previous two years on the clay loam site (Table 152). However, the two rates of sludge applied did not result in a significant difference in NO_3^--N concentration. Thus it appears that there is a substantial mineralization of sludge N in the year following sludge application although sludges did not appear to differ in this respect.

NH_4^+-N concentration in surface soils: The NH_4^+-N concentration generally did not increase with increasing rates of ammonium nitrate or sludges except for the Fe sludge on the silt loam (Table 154). The NH_4^+-N concentration as a result of sludge applications tended to be higher than that for ammonium nitrate application for the sandy loam soil (Table 153). There were no differences between sludges with respect to NH_4^+-N concentration except for that noted above.

There was no effect of previous sludge applications on the NH_4^+-N content of the clay loam soil except that the 800 kg N/ha application as Al sludge resulted in a higher concentration than the 400 kg N/ha application as ammonium nitrate (Table 155).

pH in surface soils: In general, the Ca sludge applications resulted in the highest pH values in both the sandy loam and silt loam surface soils (Tables 156 and 157). There was a tendency for the 800 kg N/ha application as Al and Fe sludges to significantly decrease the pH when compared with the 100 kg N/ha application as ammonium nitrate.

The residual effect of previous Ca sludge applications was evident on the clay loam soil (Table 158). However, the 400 kg N/ha application as ammonium nitrate significantly decreased pH.

5.2.2.3 Subsoil solution sampling. During the period April 17, 18 and 19 approximately 5.4 cm of rain fell at the Elora Research Station. This rainfall appeared to have little influence on the NO_3^--N and Cl^- concentrations at the 90 cm depth (Tables 159 and 160). The NO_3^--N concentration at the 90 cm depth was particularly high in April in the runoff experiment where 800 kg N/ha as Fe sludge was applied. This high level of NO_3^--N continued on into the fall whereas the 100 kg N/ha treatment as NH_4NO_3 was appreciably lower.

In the corn experiment, the NO_3^--N levels were high in April especially with the higher rates of sludge applied (Table 159). The highest concentrations occurred at the 45 cm depth with the 1600 kg N/ha treatments as sludge. In the fall, these treatments resulted in very high levels of NO_3^--N at the 45 cm depth which did not appear to change much over the period October 23 to December 4. In general, the NO_3^--N concentrations were higher in the fall than in the spring most probably because of the NO_3^- from the sludge application in the current year. In almost all cases, the NO_3^--N concentration exceeded the 10 µg NO_3-N/ml commonly accepted as a maximum.

The Cl^- concentrations generally coincided with the NO_3^--N concentrations. However, different sludges appeared to have contributed differently to the Cl^- concentration at the 45 cm depth (Table 160). It was not always possible to obtain a soil solution sample from all samplers because of an inadequate amount of soil solution in the soil. The numbers of samples making up each average is indicated by the number in parentheses beside each datum in Tables 159 and 160.

5.2.3 Summary and conclusions

5.2.3.1 Soil profile sampling for NO_3^-, NH_4^+ and pH. There was a considerable quantity of residual NO_3^- present at each site at the time of first sampling in April or May in 1975 with the exception of the sandy loam site. Leaching during the previous months probably caused most of the NO_3^- to disappear at this site. Also, there was insufficient time for residual sludge organic N to mineralize and nitrify before the first sampling time. The increase in NO_3^--N concentration at the June sampling showed that there was a rapid release of available N from the sludge applied following the first sampling in April/May. Leaching losses of NO_3^- appeared to be much greater in the sandy loam soil during the period from September to November although some movement of NO_3^- also occurred in the silt loam profile during this period.

There was evidence of release of available N (NO_3^-) from sludge applied the previous year on the clay loam site where sludge was not applied in 1975. However, it also appeared that there was some residual NO_3^- present in the profile from the previous year.

The NO_3^- levels were much lower in the silt loam profile under bromegrass compared with that under corn. This was observed in previous years.

Rates of sludge applied had only a small influence on the amount of exchangeable NH_4^+ present in the profile. However, as observed in the two previous years, the quantity of NH_4^+ present was usually relatively small compared with NO_3^- where sludge was applied indicating rapid nitrification.

Sludge generally had a small depressing effect on soil pH which was not always evident at each sampling on the corn experiments. Sludge applications had no apparent influence on the soil pH of the soil in the bromegrass plots.

5.2.3.2 Surface soil sampling for NO_3^-, NH_4^+ and pH. The quantity of NO_3^- present in the surface (0-15 cm) layer of soil appeared to be related to the quantity of NH_4^+ applied in the sludge. However, the sludges did not appear to differ greatly. The quantity of NO_3^- present in the surface soil at the June sampling time was approximately the same for the 800 kg N/ha treatment as sludge and the 400 kg N/ha treatment as NH_4NO_3 fertilizer. There were no differences among the sludge sources with respect to the NH_4^+ concentration in the surface soil although the highest sludge rate generally resulted in the highest NH_4^+-N concentration.

The application of Ca sludge resulted in increased soil pH values. Sludge applications in general had little influence on surface soil pH.

5.2.3.3 Subsoil solution sampling. Concentrations of NO_3^--N at the 45 and 90 cm depths in the silt loam profile at the Elora Research Station were relatively high especially at the higher rates of sludge applied. In general, the NO_3^--N concentration was higher than that normally accepted (10 µg NO_3^--N/ml). The Cl^- concentration generally tended to coincide withe the NO_3^--N concentration at the various sampling times.

5.3 Laboratory Studies on Sludge Nitrogen

5.3.1 Materials and methods

Experiment 2 was reported in part in the 1974 Sludge Research Report but was not completed at the time the report was written. A major objective of this experiment was to determine whether the aluminum sulphate treatment may be responsible for retarding the nitrification process of sludge N mixed with soil. Sludges from Tilsonburg, Kitchener, Guelph, Point Edward (1973) which were treated with aluminum sulphate were compared with sludges from North Toronto and Point Edward (1974) which were treated with ferric chloride (Table 161). Sludge was mixed with a silt loam to provide 12,000 µg sludge N in a mixture of 15 g soil and 15 g medium quartz sand. The treated soil was placed in a Buchner funnel, incubated at approximately 0.3 bar moisture and 25°C and leached weekly with distilled water. The leachates were analyzed for NO_3^--N. The experiment was terminated after 31 weeks.

A third experiment (Experiment 3) was set up to study the rate of decomposition of the organic N fraction of different sludges. Five sludges varying in N content and chemical treatment were chosen for this study (Table 162). The soluble and exchangeable NH_4^+-N fractions were removed from each sludge by centrifugation and two extractions with water then two extractions with 2 N.KCl followed by two washings with water to remove any KCl present. Water was then added to reconstitute the residual sludge to approximate the consistency of the original sludges. Each reconstituted sludge containing only organic N was then mixed with a soil-sand mixture (15 g silt loam + 15 g medium quartz sand) and placed in a Buchner funnel. The quantity of sludge mixed into the soil-sand mixture was equivalent to 12,000 µg N per 15 g soil. The sludge-treated soil-sand mixture was then immediately leached with 125 ml H_2O and incubated at approximately 25°C and 0.3 bar moisture tension. Leachates were collected weekly and analyzed for NO_3^--N. The experiment was terminated after 49 weeks. The soil-sand-sludge mixtures were then sampled and analyzed for total (Kjeldahl) N. Also, the samples were hydrolyzed in 6 N.HCl for characterization of the organic N fraction according to Bremner's method.* The organic N in these sludges was also characterized using the same procedure. Three replications of each treatment were set up.

5.3.2. Results and discussion

The accumulation of NO_3^--N from the different sludges in Experiment 2 is shown in Figure 1. The production of NO_3^--N from soil treated with the sludges was considerably different in a manner not related to the chemical treatment (Table 161). Also, the level of NH_4^+-N in the sludges did not appear to have any influence on NO_3^--N production. It is noteworthy that treatments of both Point Edward sludges resulted in much lower NO_3^--N production than the others. Thus, it appears that, although the chemical treatment of sewage at the Point Edward treatment plant has been changed from aluminum sulphate to ferric chloride, some property of the sludge inhibited nitrification at least initially. However, it is noteworthy that the new Point Edward (1974) sludge treatment resulted in a rate of NO_3^--N production which was greater than other sludges during the 16- to 32-week period. NO_3^- appeared during the second week with the North Toronto and Tilsonburg sludges and during the third week with the Guelph and Kitchener sludges. However, NO_3^- appeared during the sixth week with the Point Edward (1974) sludge treatment and during the ninth week with the Point Edward (1973) sludge treatment. The rate of NO_3^- production was relatively high during the first few weeks for the North Toronto, Tilsonburg, Guelph and Kitchener sludges, but decreased during the latter half of the incubation period. However, the rate of NO_3^- production continued to be greater with the sludge treatments than where sludge was not applied (Figure 1).

The production of NO_3^- from the organic N fraction was much greater with the North Toronto, Newmarket, Guelph and Kitchener sludges than for the new Point Edward (1974) sludge treatment (Figure 2). It appears, therefore, that some entity in the organic N fraction of this sludge was responsible for mineralization and/or nitrification inhibition. Of the total 12,000 µg of organic sludge N applied to the soil-sand mixture in each funnel, approximately two-thirds was apparently mineralized and nitrified by the end of the 49-week period. This would represent a considerable contribution of available N to a crop if this rate of mineralization of the organic N fraction occurs under field conditions. It should also be noted that mineralization of sludge organic N was still apparent at the end of the incubation period (Figure 2).

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*J.M. Bremner. 1965. Organic Forms of Nitrogen. In Methods of Soil Analysis. Pt. 2. Agron. Series No. 9, Amer. Soc. Agron. pp. 1238-1255.

The results of the N characterization study of the sludges used in Experiment 3 are presented in Table 163. The new Point Edward (1974) sludge appeared to differ from the other sludges inasmuch as the α amino acid-N and nonhydrolyzable N fractions were relatively much lower than those for the other sludges. Also, the unidentifiable hydrolyzable N was considerably higher in this sludge than in the other sludges. Reasons for these results are not apparent but may be related to the mineralization/nitrification results (Figure 2).

The 15 g soil added to each funnel contained 31.5 mg N. With the addition of 12 mg (12,000 µg)N as sludge organic N, the total N in each funnel at the beginning of the experiment amounted to 43.5 mg. During the 49-week incubation period, the soil-sand mixtures not treated with sludge lost approximately 2.7 mg N. In terms of NO_3^--N leached from the untreated soil (Figure 2), the loss was approximately 2.96 mg N. The North Toronto, New Market, Guelph and Kitchener sludge-treated soil-sand mixtures lost between 7.87 and 8.49 mg N as measured by NO_3^--N leaching. However, between 10.8 and 12.1 mg N were lost from these treatments as determined by the decrease in total (Kjeldahl) N during the 49-week incubation period. A possible reason for this discrepancy is the loss of N through NH_3 volatilization from the sludge treated soil.

Hydrolysis of the soil-sand samples at the end of the incubation period did not reveal any influence of different sludges on the characterization of organic N (Table 164).

5.3.3 Summary and conclusions

The capacity of whole sludges to produce NO_3^- when mixed with soil differed appreciably, but not in a manner which could be related to the chemical treatment or the quantity of NH_4^+-N applied in each sludge. The old Point Edward (1973) sludge produced much less NO_3^- than the new Point Edward (1974) sludge. However, the new Point Edward (1974) sludge did not produce NO_3^- as rapidly as the other sludges until the latter half of the 32-week incubation period. It appears, therefore, that some toxic substance gradually disappeared permitting nitrification to proceed in this sludge. With the old Point Edward (1973) sludge, the nitrification process was inhibited over the whole 32-week period so that little NO_3^- over that produced by the untreated soil occurred.

In most of the sludges studied, approximately two-thirds of the organic N fraction was mineralized and appeared as NO_3^- over a 49-week incubation period. The amount of organic N actually mineralized or liberated may have been greater as indicated by total N analyses of the treated soil before and after the 49-week incubation period. The new Point Edward (1974) sludge produced the least NO_3^- indicating a possible inhibition by some substance present in the sludge. Characterization of the N using hydrolysis treatment at the end of the 49-week incubation period revealed no differences between sludge source treatments. Hydrolysis of the sludges showed that the Point Edward sludge was relatively low in α-amino acid-N as well as nonhydrolyzable nitrogen.

5.4 Ammonia Volatilization Measurements in the Field

5.4.1 Materials and methods

The objective of this research was to obtain estimates of NH_3 volatilization in the field from newly applied sludge before incorporation into the soil.

Agrometeorology facilities and computerized monitors at the Elora Research Station were used to measure NH_3 flux from the surface of newly applied sludge. This experiment was conducted first during the period of May 8 to 13, 1975, and repeated during the period of October 8 to 15, 1975.

In the May experiment NH_3 flux was measured from the surface of 10,400 gallons of newly applied Al sludge from Kitchener. Sludge was applied on a circular area of one acre (0.405 hectare) on May 8. As soon as possible after application, NH_3 concentration in the atmosphere and wind speed measurements at different heights above the sludge surface were begun at 1 p.m. Measurements were obtained for each two-hour period during the first 48 hours, and thereafter for two-hour periods at 6-8 p.m., 12-2 p.m., 6-8 p.m., and 12-2 a.m. The experiment was terminated at 2 p.m. on May 13. Because of the time required for preparation and measurements for this experiment, samples of applied sludge and the soil beneath it were not taken.

The October experiment was essentially a repetition of the May experiment. Al treated sludge was obtained from Guelph and applied at a rate of 12,000 gallons on a circular area of one acre (0.405 hectare). NH_3 sampling and wind speed measurements at different heights above the sludge surface were taken during each two-hour period for 48 hours beginning at 12 noon on October 8. Thereafter until 2 p.m. on October 15, measurements and samples were taken every six hours for two-hour periods (12-2 a.m., 6-8 a.m., 12-2 p.m., 6-8 p.m.). Samples of the applied sludge layer and soil layers (0-2, 2-4, and 4-10 cm) were obtained on October 8, 9, 10, 12, 14, 16, 23, 30 and November 5 and 13. Three sampling sites (3 m x 3 m) were located in the area where sludge was applied to serve as replications. Within each sampling site, smaller areas (75 cm x 75 cm) were measured from which sludge and soil layer samples were taken. Thus at each date of sampling, one of these small areas was "used up" and was not sampled further. The sludge layer was removed with care so as to remove as little soil as possible before the 10 soil cores were taken and composited to provide a soil sample of each layer.

Atmospheric ammonia (NH_3) was absorbed in 3% phosphoric acid solution by pulling air through the acid solution. By measuring the volume of air pulled through the acid solution and the NH_3-N in the acid solution sample, it was possible to calculate the NH_3-N concentration at various heights in the air moving across the applied sludge. By applying a mathematical flux model, it was possible to obtain an estimate of the flux of NH_3 from the sludge surface over time.

The pH, exchangeable NH_4^+ and NO_3^- concentrations in the applied sludge and soil layer samples were determined in the manner previously indicated.

5.4.2 Results and discussion

The total NH_3-N volatilized each day during the experimental periods in May and October is presented in Table 165. In both cases, the amount of NH_3 volatilized decreased over the experimental period. It is noteworthy that the quantity lost each day in the October experiment was much lower than that lost during the May experiment. This may be explained in part by the smaller quantity of NH_4^+-N applied for the October experiment (Table 165). It is also noteworthy that approximately 48% of the NH_4^+-N was volatilized in the May experiment whereas 41% of the NH_4^+-N was volatilized during the October experiment. The lower percentage volatilized during the October experiment may be due to differences in weather conditions. Warm, sunny weather was mostly prevalent in the May experiment whereas cloudy, cool weather with occasional rain showers prevailed during most of the October experiment.

The NH_4^+-N and NO_3^--N concentrations in the sludge and soil layer samples and H_2O content and pH of the soil layer samples taken from beneath the applied sludge are presented in Table 166. The H_2O content of the sludge was inadvertently not determined, which unfortunately obviated the valid estimates of NH_4^+-N and NO_3^--N contents in the sludge layer. This resulted in being unable to calculate a N balance sheet and thereby estimate losses of NH_3-N through volatilization by another method.

The NO_3^--N content in the soil layers increased almost immediately after sludge was applied. This meant that sludge liquid containing NH_4^+ had moved into the soil following application and nitrification of the NH_4^+ ions to NO_3^- ions was rapidly occurring. Although the NH_4^+ ions tended to be concentrated in the 0-2 cm soil layer, high NO_3^--N concentration occurred in the 2-4 and 4-10 cm layers. Part of this distribution was due to rainfall which occurred in small quantities each day from October 9 to 12 and on October 13 (1.4 cm). This rainfall event reflected the higher H_2O content and lower NO_3^--N concentration because of leaching and/or denitrification and the increase in NH_4^+ leached from the sludge layer. The steady decrease in NH_4^+-N concentration in the 0-2 cm layer from October 14 to November 13 was mostly due to nitrification. However, the NO_3^--N concentration changed in a variable manner indicating leaching and possibly denitrification losses and gains from nitrification of NH_4^+ in the soil layers.

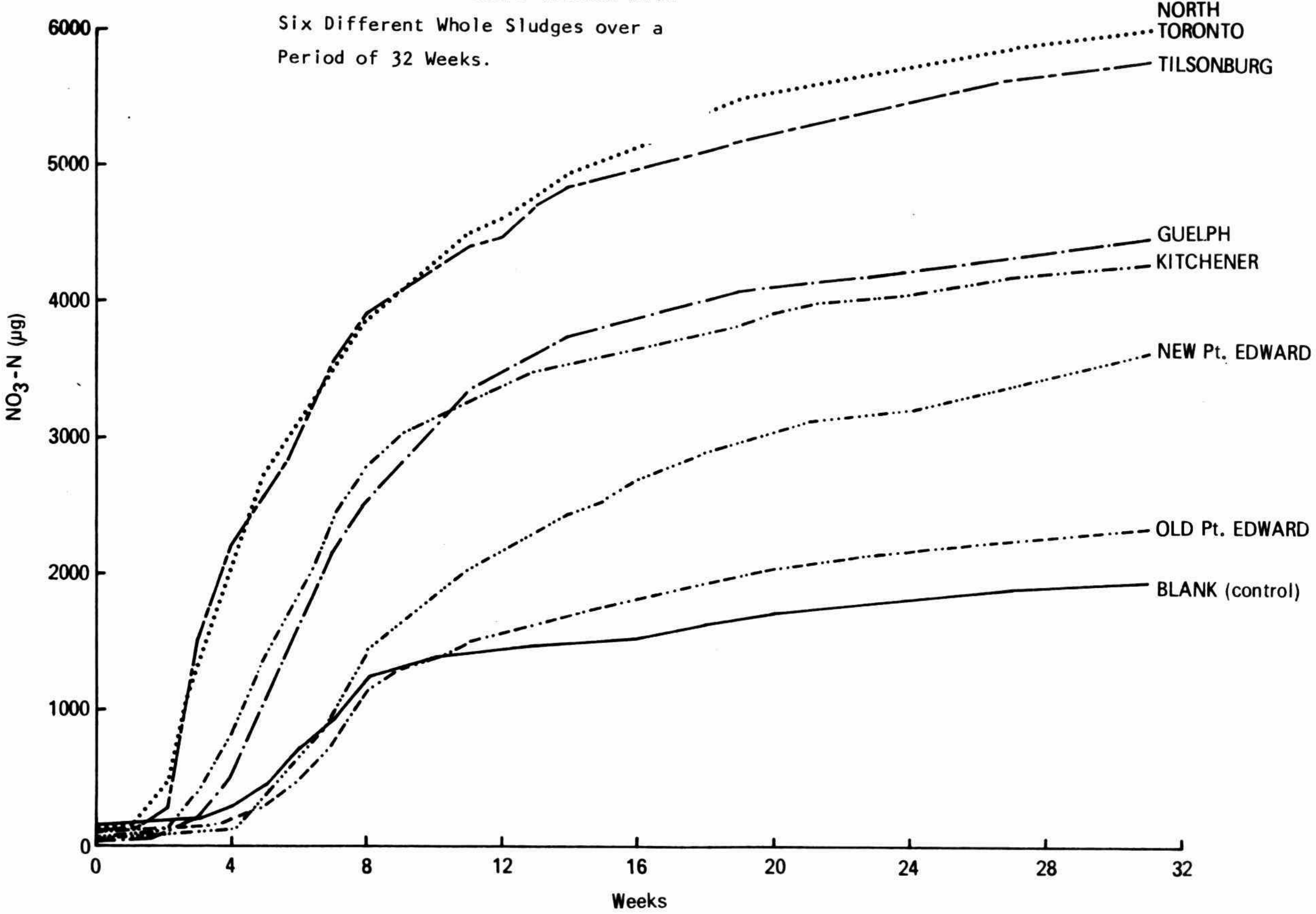
The pH of the soil layers did not appear to be affected by sludge application nor from the nitrification of NH_4^+ which is an acidifying process.

5.4.3 Summary and conclusions

Field studies on NH_3 volatilization from sludge applied to the soil surface showed that 48% of the NH_4^+-N in the sludge was lost during a five-day period in May while 41% of the NH_4^+-N in the sludge was lost during a seven-day period in October. The amount of NH_3 volatilized appeared to be related more to the amount of NH_4^+-N applied in the sludge than on prevalent weather conditions.

The NH_4^+ in sludge liquid moving into the soil immediately following sludge application was rapidly nitrified within a few days in the 0-2 cm soil layer. The NO_3^- formed was leached into the lower soil layers when rainfall occurred.

Figure 1. NO_3^--N Production During Incubation of a Soil-sand Mixture Treated with Six Different Whole Sludges over a Period of 32 Weeks.



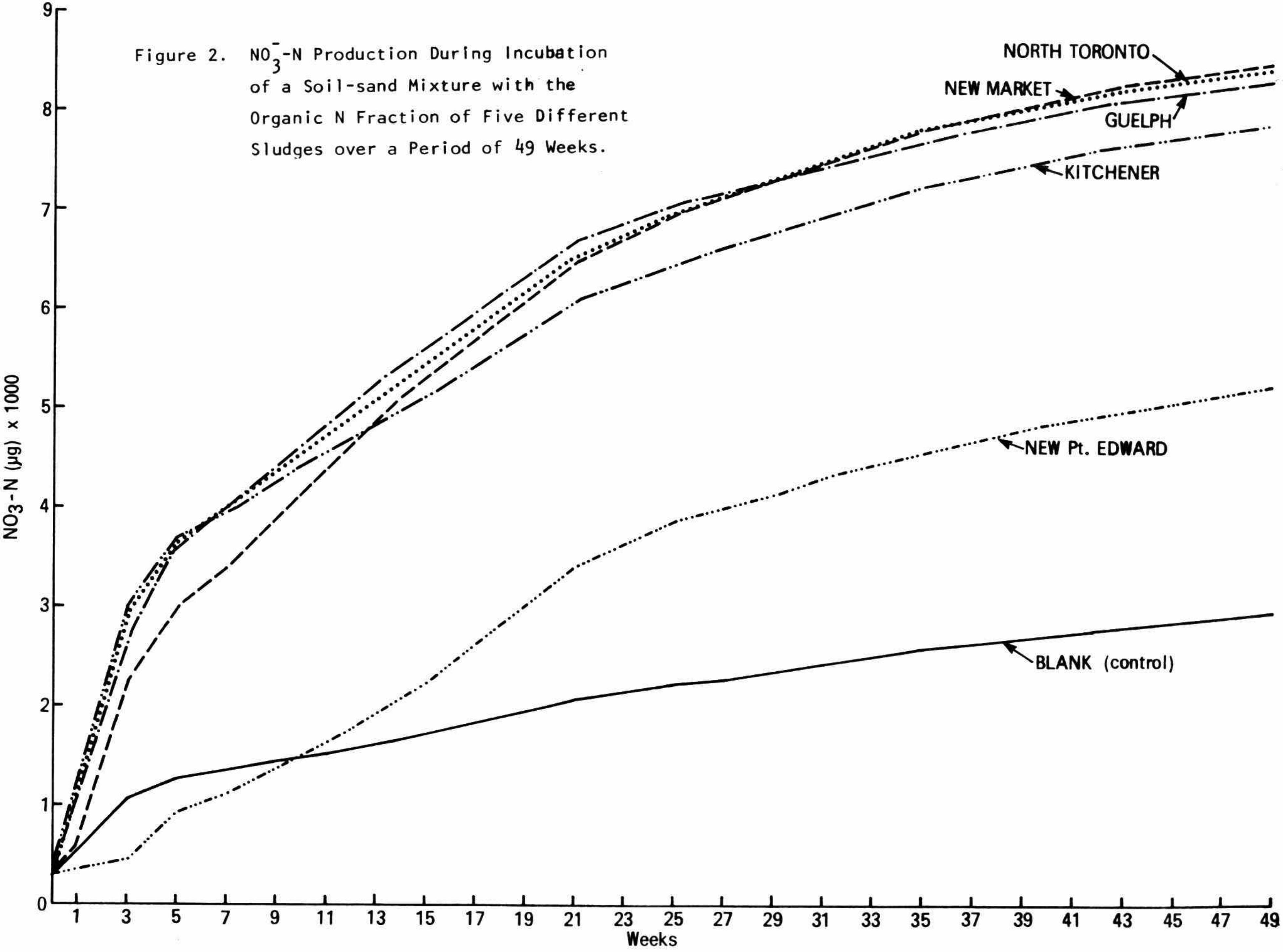


Figure 2. NO_3^--N Production During Incubation of a Soil-sand Mixture with the Organic N Fraction of Five Different Sludges over a Period of 49 Weeks.

TABLE 138. NO_3-N Concentration in Sandy Loam Soil Profile (Cambridge Corn Experiment) in Plots Having Received Different Quantities of Iron-treated Sludge. Sampled April 22, June 27, September 15, and November 27, 1975.

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)			Significance of Effect*		
	In	(cm)	0	356(400)	712(800)	Depth	Rate	D x R
			NO_3-N µg/g					
22/4/75	0- 6	(0-15)	2.4	3.3	3.0	N.S.	N.S.	N.S.
	6-12	(15-30)	3.8	3.5	3.1			
	12-18	(30-45)	4.2	5.4	3.4			
	18-24	(45-60)	5.9	6.5	5.5			
	24-36	(60-90)	4.3	4.4	5.0			
27/6/75	0- 6	(0-15)	16.3	38.4	82.8	.005	.005	.005
	6-12	(15-30)	13.1	34.1	49.4			
	12-18	(30-45)	6.8	17.7	36.5			
	18-24	(45-60)	3.1	7.8	7.6			
	24-36	(60-90)	4.2	10.4	7.1			
15/9/75	0- 6	(0-15)	4.6	6.7	10.2	.005	.005	N.S.
	6-12	(15-30)	6.0	17.1	27.8			
	12-18	(30-45)	4.8	18.5	25.9			
	18-24	(45-60)	4.8	12.3	26.0			
	24-36	(60-90)	3.3	5.8	15.9			
27/11/75	0- 6	(0-15)	3.1	3.7	7.6	.05	.005	N.S.
	6-12	(15-30)	4.1	7.4	12.0			
	12-18	(30-45)	3.7	7.9	10.5			
	18-24	(45-60)	2.6	8.4	10.9			
	24-36	(60-90)	1.5	6.2	10.6			

*0.05, 0.01 and 0.005 indicate level of significance. N.S. indicates effect not significant at 0.05 level of probability.

TABLE 139. NO_3-N Concentration in Silt Loam Soil Profile (Elora Corn Experiment) in Plots Having Received Different Quantities of Iron-treated Sludge. Sampled April 23, June 24, September 17, and November 25, 1975.

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)			Significance of Effect*		
	In	(cm)	0	356(400)	712(800)	Depth	Rate	D x R
				NO_3-N µg/g				
23/4/75	0- 6	(0-15)	9.6	13.3	13.4	.005	.005	.005
	6-12	(15-30)	7.8	22.5	22.8			
	12-18	(30-45)	6.8	16.6	24.7			
	18-24	(45-60)	4.5	11.7	18.5			
	24-36	(60-90)	4.2	10.6	12.5			
24/6/75	0- 6	(0-15)	34.3	96.0	126	.005	.005	.005
	6-12	(15-30)	18.7	56.9	67.4			
	12-18	(30-45)	14.2	32.8	39.3			
	18-24	(45-60)	7.5	13.0	21.4			
	24-36	(60-90)	7.9	16.0	23.0			
17/9/75	0- 6	(0-15)	5.1	52.6	48.1	.005	.005	.005
	6-12	(15-30)	2.3	76.1	74.3			
	12-18	(30-45)	1.7	23.8	53.8			
	18-24	(45-60)	1.5	12.1	31.0			
	24-36	(60-90)	2.2	8.4	12.7			
25/11/75	0- 6	(0-15)	8.9	29.4	30.7	.005	.005	N.S.
	6-12	(15-30)	6.2	43.8	58.2			
	12-18	(30-45)	3.1	59.8	76.1			
	18-24	(45-60)	2.2	39.9	51.0			
	24-36	(60-90)	5.4	21.6	26.0			

*0.05, 0.01 and 0.005 indicate level of significance. N.S. indicates effect not significant at 0.05 level of probability.

TABLE 140. NO_3-N Concentration in Clay Loam Soil Profile (Milton Corn Experiment) in Plots Having Received Different Quantities of Iron-treated Sludge. Sampled May 12, June 25, and September 16, 1975.

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)				Significance of Effect*		
	In	(cm)	0	356(400)	712(800)	1428(1600)	Depth	Rate	D x R
			NO_3-N µg/g						
12/5/75	0- 6	(0-15)	20.1	23.0	24.9	-	.005	.005	N.S.
	6-12	(15-30)	14.7	15.4	21.6	-			
	12-18	(30-45)	10.5	13.5	17.4	-			
	18-24	(45-60)	7.8	8.7	14.2	-			
	24-36	(60-90)	4.4	5.8	8.4	-			
25/6/75	0- 6	(0-15)	47.6	36.9	44.3	53.7	.005	.005	N.S.
	6-12	(15-30)	23.4	20.5	40.1	34.6			
	12-18	(30-45)	15.8	16.6	26.4	34.1			
	18-24	(45-60)	12.8	11.3	16.7	22.6			
	24-36	(60-90)	13.7	9.8	12.5	19.3			
16/9/75	0- 6	(0-15)	27.3	38.5	48.6	40.5	.005	.005	N.S.
	6-12	(15-30)	8.5	11.4	25.4	33.0			
	12-18	(30-45)	3.5	4.4	12.7	23.4			
	18-24	(45-60)	3.1	3.8	10.9	17.4			
	24-36	(60-90)	2.5	4.5	9.2	13.4			

*0.05, 0.01 and 0.005 indicate level of significance. N.S. indicates effect not significant at 0.05 level of probability.

TABLE 141. NO_3-N Concentration in Silt Loam Soil Profile (Elora Bromegrass) in Plots Having Received Different Quantities of Iron-treated Sludge. Sampled April 23, June 9, September 30, and November 26, 1975.

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)			Significance of Effect*		
	In	(cm)	0	356(400)	712(800)	Depth	Rate	D x R
			NO_3-N µg/g					
23/4/75	0- 6	(0-15)	3.7	5.2	7.2	.005	.005	N.S.
	6-12	(15-30)	2.2	3.1	5.0			
	12-18	(30-45)	1.8	2.5	3.3			
	18-24	(45-60)	2.4	1.6	3.0			
	24-36	(60-90)	2.3	2.0	2.9			
9/6/75	0- 6	(0-15)	3.8	9.0	17.0	.005	.005	.005
	6-12	(15-30)	1.8	4.3	6.0			
	12-18	(30-45)	1.1	2.1	3.9			
	18-24	(45-60)	0.5	1.8	3.0			
	24-36	(60-90)	0.6	2.0	2.4			
30/9/75	0- 6	(0-15)	4.3	8.4	23.2	N.S.	.005	N.S.
	6-12	(15-30)	0.7	8.4	32.4			
	12-18	(30-45)	2.4	5.8	25.4			
	18-24	(45-60)	2.7	4.4	15.1			
	24-36	(60-90)	2.6	3.5	6.7			
26/11/75	0- 6	(0-15)	1.5	3.3	11.4	.005	.005	.005
	6-12	(15-30)	1.5	2.2	20.7			
	12-18	(30-45)	0.6	1.6	25.4			
	18-24	(45-60)	0.8	0.4	16.5			
	24-36	(60-90)	0.7	0.8	7.2			

*0.05, 0.01 and 0.005 indicate level of significance. N.S. indicates effect not significant at 0.05 level of probability.

TABLE 142. NH_4-N Concentration in Sandy Loam Soil Profile (Cambridge Corn Experiment) in Plots Having Received Different Quantities of Iron-treated Sludge, Sampled April 22, June 27, September 15, and November 27, 1975.

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)			Significance of Effect*		
	In	(cm)	0	356(400)	712(800)	Depth	Rate	D x R
			NH_4-N µg/g					
22/4/75	0- 6	(0-15)	3.7	4.0	7.8	.005	N.S.	N.S.
	6-12	(15-30)	2.6	2.4	2.6			
	12-18	(30-45)	1.6	2.1	2.1			
	18-24	(45-60)	1.4	1.3	1.4			
	24-36	(60-90)	1.3	1.2	1.1			
27/6/75	0- 6	(0-15)	5.7	7.3	7.4	.005	N.S.	N.S.
	6-12	(15-30)	3.6	4.7	3.7			
	12-18	(30-45)	3.1	3.2	4.0			
	18-24	(45-60)	2.1	2.3	2.1			
	24-36	(60-90)	2.1	1.9	2.0			
15/9/75	0- 6	(0-15)	3.6	2.3	4.6	.005	.005	.01
	6-12	(15-30)	2.4	1.9	3.0			
	12-18	(30-45)	1.7	1.1	2.2			
	18-24	(45-60)	1.3	1.0	1.7			
	24-36	(60-90)	1.2	0.8	1.5			
27/11/75	0- 6	(0-15)	3.5	2.9	4.3	.005	.05	N.S.
	6-12	(15-30)	2.8	2.1	2.9			
	12-18	(30-45)	1.3	1.0	1.0			
	18-24	(45-60)	1.8	1.0	1.3			
	24-36	(60-90)	1.1	1.1	1.0			

*0.05, 0.01 and 0.005 indicate level of significance. N.S. indicates effect not significant at 0.05 level of probability.

TABLE 143. NH_4-N Concentration in Silt Loam Soil Profile (Elora Corn Experiment) in Plots Having Received Different Quantities of Iron-treated Sludge. Sampled April 23, June 24, September 17, and November 25, 1975.

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)			Significance of Effect*		
	In	(cm)	0	356(400)	712(800)	Depth	Rate	D x R
				NH_4-N µg/g				
23/4/75	0- 6	(0-15)	3.9	4.5	1.8	.005	N.S.	N.S.
	6-12	(15-30)	4.9	4.6	4.7			
	12-18	(30-45)	4.2	4.9	3.3			
	18-24	(45-60)	2.5	2.9	2.2			
	24-36	(60-90)	2.1	2.3	1.7			
24/6/75	0- 6	(0-15)	4.7	6.1	11.8	.005	.05	.005
	6-12	(15-30)	4.1	5.0	4.5			
	12-18	(30-45)	2.8	3.8	3.0			
	18-24	(45-60)	2.1	2.2	2.0			
	24-36	(60-90)	2.1	2.0	2.0			
17/9/75	0- 6	(0-15)	5.7	5.7	5.6	.005	N.S.	N.S.
	6-12	(15-30)	3.9	4.2	4.3			
	12-18	(30-45)	2.4	2.8	2.8			
	18-24	(45-60)	2.2	2.2	2.3			
	24-36	(60-90)	2.1	1.7	1.6			
25/11/75	0- 6	(0-15)	4.6	5.0	4.0	.005	.005	N.S.
	6-12	(15-30)	3.4	4.0	3.0			
	12-18	(30-45)	2.1	2.9	2.3			
	18-24	(45-60)	1.4	1.4	1.1			
	24-36	(60-90)	1.2	1.3	0.9			

*0.05, 0.01 and 0.005 indicate level of significance. N.S. indicates effect not significant at 0.05 level of probability.

TABLE 144. NH_4-N Concentration in Clay Loam Soil Profile (Milton Corn Experiment) in Plots Having Received Different Quantities of Iron-treated sludge. Sampled May 12, June 25, and September 16, 1975.

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)				Significance of Effect*		
	In	(cm)	0	356(400)	712(800)	1428(1600)	Depth	Rate	D x R
				NH_4-N µg/g					
12/5/75	0- 6	(0-15)	4.7	6.5	6.0	-	.005	N.S.	N.S.
	6-12	(15-30)	4.8	4.9	5.3	-			
	12-18	(30-45)	3.1	4.1	3.6	-			
	18-24	(45-60)	3.1	3.0	3.1	-			
	24-36	(60-90)	2.4	3.0	2.4	-			
25/6/75	0- 6	(0-15)	6.5	7.1	5.7	10.4	.005	.05	N.S.
	6-12	(15-30)	5.4	5.7	5.8	7.9			
	12-18	(30-45)	4.1	4.9	3.9	4.0			
	18-24	(45-60)	3.1	2.9	3.3	3.4			
	24-36	(60-90)	2.4	2.2	3.2	2.8			
16/9/75	0- 6	(0-15)	4.2	4.8	6.7	6.7	.005	.005	N.S.
	6-12	(15-30)	3.6	3.8	3.9	4.7			
	12-18	(30-45)	2.7	2.3	2.5	2.9			
	18-24	(45-60)	1.9	1.8	2.1	2.2			
	24-36	(60-90)	1.4	1.4	1.9	2.0			

*0.05, 0.01 and 0.005 indicate level of significance. N.S. indicates effect not significant at 0.05 level of probability.

TABLE 145. NH_4-N Concentration in Silt Loam Soil Profile (Elora Bromegrass) in Plots Having Received Different Quantities of Iron-treated Sludge. Sampled April 24, June 9, September 30, and November 26, 1975.

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)			Significance of Effect*		
	In	(cm)	0	356(400)	712(800)	Depth	Rate	D x R
				NH_4-N µg/g				
23/4/75	0- 6	(0-15)	7.0	7.2	11.1	.005	.005	N.S.
	6-12	(15-30)	3.9	5.4	7.9			
	12-18	(30-45)	1.9	3.1	5.0			
	18-24	(45-60)	1.6	2.3	3.2			
	24-36	(60-90)	1.5	1.2	1.2			
9/6/75	0- 6	(0-15)	6.3	6.3	7.2	.005	.005	N.S.
	6-12	(15-30)	5.2	5.7	6.4			
	12-18	(30-45)	3.0	3.7	4.6			
	18-24	(45-60)	2.2	2.4	2.7			
	24-36	(60-90)	2.3	2.2	2.2			
30/9/75	0- 6	(0-15)	5.8	6.2	5.7	.005	N.S.	N.S.
	6-12	(15-30)	3.6	5.1	4.1			
	12-18	(30-45)	2.1	3.0	2.5			
	18-24	(45-60)	1.8	1.9	2.2			
	24-36	(60-90)	1.4	2.1	1.7			
26/11/75	0- 6	(0-15)	7.0	7.0	7.2	.005	N.S.	N.S.
	6-12	(15-30)	4.5	4.8	4.5			
	12-18	(30-45)	1.6	2.7	2.5			
	18-24	(45-60)	1.5	1.4	1.3			
	24-36	(60-90)	1.0	1.2	1.1			

*0.05, 0.01 and 0.005 indicate level of significance. N.S. indicates effect not significant at 0.05 level of probability.

TABLE 146. pH of Sandy Loam Soil Profile (Cambridge Corn Experiment) of Plots Having Received Different Quantities of Iron-treated Sludge. Sampled April 22, June 27, September 15, and November 27, 1975.

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)			Significance of Effect*		
	In	(cm)	0	356(400)	712(800)	Depth	Rate	D x R
				pH				
22/4/75	0- 6	(0-15)	7.9	7.6	7.7	.005	N.S.	N.S.
	6-12	(15-30)	7.9	7.8	7.9			
	12-18	(30-45)	8.0	7.9	8.0			
	18-24	(45-60)	8.1	8.1	8.1			
	24-36	(60-90)	8.2	8.3	8.2			
27/6/75	0- 6	(0-15)	7.6	7.3	7.3	.005	.01	N.S.
	6-12	(15-30)	7.7	7.4	7.5			
	12-18	(30-45)	7.8	7.6	7.5			
	18-24	(45-60)	7.9	7.8	7.9			
	24-36	(60-90)	8.0	7.8	8.0			
15/9/75	0- 6	(0-15)	7.2	7.1	7.3	.005	N.S.	N.S.
	6-12	(15-30)	7.3	7.2	7.2			
	12-18	(30-45)	7.4	7.3	7.2			
	18-24	(45-60)	7.5	7.4	7.3			
	24-36	(60-90)	7.5	7.6	7.4			
27/11/75	0- 6	(0-15)	7.7	7.7	7.7	N.S.	.01	N.S.
	6-12	(15-30)	7.7	7.7	7.5			
	12-18	(30-45)	7.7	7.5	7.6			
	18-24	(45-60)	7.7	7.6	7.6			
	24-36	(60-90)	7.8	7.6	7.7			

*0.05, 0.01 and 0.005 indicate level of significance. N.S. indicates effect not significant at 0.05 level of probability.

TABLE 147. pH of Silt Loam Soil Profile (Elora Corn Experiment) of Plots Having Received Different Quantities of Iron-treated Sludge. Sampled April 23, June 24, September 17, and November 25, 1975

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)			Significance of Effect*		
	In	(cm)	0	356(400)	712(800)	Depth	Rate	D x R
				pH				
23/4/75	0- 6	(0-15)	7.5	7.3	7.4	N.S.	.05	N.S.
	6-12	(15-30)	7.5	7.3	7.4			
	12-18	(30-45)	7.5	7.4	7.4			
	18-24	(45-60)	7.3	7.4	7.5			
	24-36	(60-90)	7.6	7.4	7.5			
24/6/75	0- 6	(0-15)	7.6	7.5	7.3	.005	.005	.005
	6-12	(15-30)	7.7	7.6	7.5			
	12-18	(30-45)	7.8	7.7	7.7			
	18-24	(45-60)	8.0	8.0	7.7			
	24-36	(60-90)	8.0	7.9	7.8			
17/9/75	0- 6	(0-15)	7.7	7.5	7.7	.01	N.S.	N.S.
	6-12	(15-30)	7.7	7.5	7.6			
	12-18	(30-45)	7.8	7.7	7.7			
	18-24	(45-60)	7.9	7.9	7.8			
	24-36	(60-90)	8.0	8.0	8.0			
25/11/75	0- 6	(0-15)	7.9	7.6	7.7	.005	.005	N.S.
	6-12	(15-30)	7.8	7.5	7.7			
	12-18	(30-45)	7.8	7.5	7.7			
	18-24	(45-60)	8.0	7.7	7.9			
	24-36	(60-90)	8.1	7.8	8.2			

*0.05, 0.01 and 0.005 indicate level of significance. N.S. indicates effect not significant at 0.05 level of probability.

TABLE 148. pH of Clay Loam Soil Profile (Milton Corn Experiment) of Plots Having Received Different Quantities of Iron-treated Sludge. Sampled May 12, June 25, and September 16, 1975.

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)				Significance of Effect*		
	In	(cm)	0	356(400)	712(800)	1428(1600)	Depth	Rate	D x R
12/5/75	0- 6	(0-15)	7.3	7.3	7.2	-	.005	N.S.	N.S.
	6-12	(15-30)	6.9	7.2	7.1	-			
	12-18	(30-45)	7.2	7.2	7.4	-			
	18-24	(45-60)	7.8	7.7	7.7	-			
	24-36	(60-90)	7.9	7.9	7.9	-			
25/6/75	0- 6	(0-15)	7.1	6.9	7.0	6.8	.005	N.S.	N.S.
	6-12	(15-30)	6.9	6.6	6.7	6.7			
	12-18	(30-45)	7.0	6.8	7.1	6.5			
	18-24	(45-60)	7.5	7.4	7.4	7.1			
	24-36	(60-90)	7.7	7.7	7.6	7.6			
16/9/75	0- 6	(0-15)	6.8	6.9	7.0	7.1	.005	N.S.	N.S.
	6-12	(15-30)	6.6	6.7	7.1	6.9			
	12-18	(30-45)	6.9	6.8	7.1	7.0			
	18-24	(45-60)	7.4	7.3	7.5	7.3			
	24-36	(60-90)	7.6	7.7	7.9	7.8			

*0.05, 0.01 and 0.005 indicate level of significance. N.S. indicates effect not significant at 0.05 level of probability.

TABLE 149. pH of Silt Loam Soil Profile (Elora Bromegrass) of Plots Having Received Different Quantities of Iron-treated Sludge. Sampled April 23, June 9, September 30, and November 26, 1975.

Date	Depth		Sludge Rate-lb N/ac (kg N/ha)			Significance of Effect*		
	In	(cm)	0	356(400)	712(800)	Depth	Rate	D x R
				pH				
23/4/75	0- 6	(0-15)	7.6	7.6	7.5	.005	N.S.	N.S.
	6-12	(15-30)	7.6	7.6	7.5			
	12-18	(30-45)	7.6	7.7	7.6			
	18-24	(45-60)	7.7	7.8	7.7			
	24-36	(60-90)	7.8	7.7	7.8			
9/6/75	0- 6	(0-15)	7.6	7.4	7.5	.005	N.S.	N.S.
	6-12	(15-30)	7.6	7.6	7.6			
	12-18	(30-45)	7.7	7.7	7.7			
	18-24	(45-60)	7.7	7.9	7.9			
	24-36	(60-90)	7.8	8.0	8.0			
30/9/75	0- 6	(0-15)	7.9	7.6	7.7	.005	N.S.	N.S.
	6-12	(15-30)	7.8	7.6	7.6			
	12-18	(30-45)	7.9	7.8	7.7			
	18-24	(45-60)	7.9	7.9	7.9			
	24-36	(60-90)	8.0	8.1	8.1			
26/11/75	0- 6	(0-15)	7.8	7.6	7.8	.005	N.S.	N.S.
	6-12	(15-30)	7.8	7.7	7.7			
	12-18	(30-45)	7.7	7.8	7.8			
	18-24	(45-60)	8.0	7.9	7.9			
	24-36	(60-90)	8.0	8.1	8.1			

*0.05, 0.01 and 0.005 indicate level of significance. N.S. indicates effect not significant at 0.05 level of probability.

TABLE 150. NO_3-N Concentration of 0-6 in (0-15 cm) Soil Samples Taken from Cambridge Corn Experiment (Sandy Loam) on June 25, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			μg NO_3-N/g		
89 (100)	50 bc*				
356 (400)	89 a	43 c	55 abc	58 abc	52
712 (800)		77 abc	89 a	83 ab	83
Average	69	60	72	70	

Rates of nitrogen are significantly different at 0.01 probability level.

* Mean values followed by the same letter are not significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

TABLE 151. NO_3-N Concentration in 0-6 in (0-15 cm) Soil Samples Taken from Elora Corn Experiment (Silt Loam) on June 24, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			μg NO_3-N/g		
89 (100)	50 d*				
356 (400)	139 a	79 cd	87 bcd	96 bc	87
712 (800)		106 abc	139 a	126 ab	127
Average	94	92	113	111	

Rates of nitrogen are significantly different at 0.01 probability level by "F" test.

* Mean values followed by a common letter are not significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

TABLE 152. NO_3-N Concentration in 0-6 in (0-15 cm) Soil Samples Taken from Elora Corn Experiment (Clay Loam) on June 25, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			μg NO_3-N/g		
89 (100)	26 b*				
356 (400)	48 a	35 ab	38 ab	37 ab	37
712 (800)		51 a	43 ab	44 a	46
Average	37	43	41	41	

* Mean values followed by a common letter are not significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Rates of nitrogen are significantly different at 0.01 probability level by "F" test.

TABLE 153. NH_4-N Concentration in 0-6 in (0-15 cm) Soil Samples Taken from Cambridge Corn Experiment (Sandy Loam) on June 25, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			µg NH_4-N/g		
89 (100)	4.4 ^{c*}				
356 (400)	4.4 ^{c}	4.8 ^{bc}	5.1 ^{abc}	7.3 ^{a}	5.7
712 (800)		5.2 ^{abc}	7.0 ^{ab}	7.4 ^{a}	6.5
Average	4.4	5.0	6.1	7.3	

Nitrogen sources are significantly different at 0.01 probability level by 'F' test.

* Mean values followed by a common letter are not significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

TABLE 154. NH_4-N Concentration in 0-6 in (0-15 cm) Soil Samples Taken from Elora Corn Experiment (Silt Loam) on June 24, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			µg NH_4-N/g		
89 (100)	4.9 ^{b*}				
356 (400)	4.6 ^{b}	7.2 ^{b}	6.8 ^{b}	6.1 ^{b}	6.7
712 (800)		7.9 ^{b}	8.0 ^{b}	11.7 ^{a}	9.2
Average	4.75	7.55	7.4	8.9	

Nitrogen sources and rates are significantly different at 0.05 probability level by 'F' test.

* Mean values followed by a common letter are not significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

TABLE 155. NH_4-N Concentration in 0-6 in (0-15 cm) Soil Samples Taken from Milton Corn Experiment (Clay Loam) on June 25, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			µg NH_4-N/g		
89 (100)	6.0 ab*				
356 (400)	5.7 b	7.3 ab	7.5 ab	7.0 ab	7.3
712 (800)		7.8 ab	8.6 a	5.7 b	7.4
Average	5.8	7.5	8.1	6.4	

* Mean values followed by a common letter are not significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Sources of nitrogen are significantly different at 0.05 probability level by "F" test.

TABLE 156. pH† of 0-6 in (0-15 cm) Soil Samples Taken from Cambridge Corn Experiment (Sandy Loam) on June 25, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
89 (100)	7.49 b*				
356 (400)	7.45 b	8.17 a	7.57 b	7.35 b	7.70
712 (800)		8.15 a	7.47 b	7.26 b	7.63
Average	7.47	8.16	7.52	7.30	

Nitrogen sources are significantly different at 0.01 probability level by "F" test.

* Mean values followed by a common letter are not significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

† In 1:2 soil:water slurry.

TABLE 157. pH† of 0-6 in (0-15 cm) Soil Samples Taken from Elora Corn Experiment (Silt Loam) on June 25, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
89 (100)	7.78 b*				
356 (400)	7.52 bc	8.11 a	7.59 bc	7.51 bc	7.74
712 (800)		8.12 a	7.41 c	7.29 c	7.61
Average	7.65	8.12	7.50	7.40	

Nitrogen sources are significantly different at 0.01 probability level by "F" test.

Nitrogen rates are significantly different at 0.05 probability level by "F" test.

* Mean values followed by a common letter are not significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

† In 1:2 soil:water slurry.

TABLE 158. pH[†] of 0-6 in (0-15 cm) Soil Samples Taken from Milton Corn Experiment (Clay Loam) on June 25, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
89 (100)	7.15 b*				
356 (400)	6.19 c	8.02 a	7.06 b	6.91 b	7.33
712 (800)		8.07 a	7.17 b	7.00 b	7.41
Average	6.67	8.05	7.12	6.95	

Nitrogen sources are significantly different at 0.01 probability level by the "F" test.

Source x rate interaction is significant at 0.01 probability level.

* Mean values followed by a common letter are not significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

† In 1:2 soil:water slurry.

TABLE 159. NO_3-N Concentration in Subsurface Soil Solution Samples Taken During 1975 from the Corn Experiment or Runoff Experiment at the Elora Research Station.

Site	Treatment	April 14	April 16	April 22	Oct. 23	Nov. 6	Nov. 20	Dec. 4
				(µg NO_3-N/ml)				
Runoff Expt. (sludge applied in spring)	NH_4NO_3; 100 kg N/ha	13(4)*	41(4)	15(4)	20(4)	9(4)	9(4)	9(4)
	Fe sludge; 800 kg N/ha	55(4)	47(4)	51(4)	70(4)	67(4)	54(4)	60(4)
Corn Expt.	NH_4NO_3; 100 kg N/ha	42(3)	42(3)	38(3)	70(1)	71(3)	75(2)	74(2)
	NH_4NO_3; 200 kg N/ha (†)	64(2)	84(3)	57(3)	87(2)	75(3)	73(3)	70(3)
	NH_4NO_3; 400 " "	26(3)	67(3)	88(3)	123(2)	125(3)	92(3)	160(3)
	Fe sludge; 200 kg N/ha	36(3)	41(3)	38(3)	76(2)	44(2)	42(2)	45(2)
	" " ; 400 " "	39(3)	32(3)	59(3)	70(2)	53(2)	50(2)	65(2)
	" " ; 800 " "	42(3)	51(3)	77(2)	74(2)	83(2)	90(2)	100(2)
	" " ; 1600 " " (†)	147(3)	126(3)	183(3)	467(3)	554(3)	530(3)	537(3)
	Ca sludge; 1600 " " (†)	149(3)	144(3)	104(3)	341(3)	458(3)	570(3)	540(3)
	Al sludge; 1600 " " (†)	153(1)	137(3)	170(3)	405(3)	447(3)	375(2)	445(3)

† Samples were collected at the 90 cm depth except those with (†) which were sampled at the 45 cm depth.
* Numbers in parenthesis indicate number of replications sampled.

TABLE 160. Chloride Concentration in Subsurface Soil Solution Samples Taken During 1975 from the Corn Experiment or Runoff Experiment at the Elora Research Station.

Site	Treatment	April 14	April 16	April 22	Oct. 23	Nov. 6	Nov. 20	Dec. 4
				(µg Cl^-/ml)				
Runoff Expt. (sludge applied in spring)	NH_4NO_3; 100 kg N/ha	25(4)*	22(4)	20(4)	20(4)	20(4)	19(4)	23(4)
	Fe sludge; 800 kg N/ha	33(3)	25(4)	20(4)	27(4)	31(4)	25(4)	33(4)
Corn Expt.	NH_4NO_3; 100 kg N/ha	34(3)	31(3)	27(3)	38(1)	47(3)	52(2)	47(2)
	" ; 200 " " (†)	32(2)	33(3)	23(3)	103(2)	77(3)	69(3)	67(3)
	" ; 400 " "	10(3)	22(3)	29(3)	32(2)	33(3)	42(3)	46(3)
	Fe sludge; 200 kg N/ha	56(3)	57(3)	54(3)	34(2)	58(1)	57(2)	58(2)
	" " ; 400 " "	29(3)	24(3)	36(3)	47(1)	34(2)	31(2)	42(2)
	" " ; 800 " "	35(3)	40(3)	58(2)	44(2)	46(2)	55(2)	59(2)
	" " ; 1600 " " (†)	58(3)	42(3)	61(3)	164(3)	172(3)	165(3)	152(3)
	Ca sludge; 1600 " " (†)	98(3)	67(3)	55(3)	236(3)	263(3)	262(3)	255(2)
	Al sludge; 1600 " " (†)	74(3)	73(3)	57(3)	120(3)	120(3)	106(2)	117(3)

† Samples were collected at the 90 cm depth except those with (†) which were sampled at the 45 cm depth. * Numbers in parenthesis indicate number of replications sampled.

TABLE 161. Total Nitrogen and Soluble Exchangeable NH_4^+ in Six Sludges Used in the Laboratory Studies (Experiment 2).

Sludge Source	Treatment	Sludge N Fractions Total N*	 Soluble NH_4^+ - N	 Exchangeable NH_4^+ - N*
		%	(µg/g)	(µg/g)
North Toronto	$FeCl_3$	0.30	913	63
Pt. Edward (1973)	$Al_2(SO_4)_3$	0.10	400	25
Pt. Edward (1974)	$FeCl_3$	0.31	588	63
Kitchener	$Al_2(SO_4)_3$	0.28	1250	84
Guelph	$Al_2(SO_4)_3$	0.17	613	38
Tillsonburg	$Al_2(SO_4)_3$	0.17	555	61

* fluid basis

TABLE 162. Nitrogen Composition of Original Sludges, Total Organic Nitrogen Lost in NH_4^+ Removal Procedure, and Total Organic Nitrogen Composition of Reconstituted Sludges Used in Laboratory Experiment 3.

Sludge Source	Treatment	Date Sampled	Original Composition*				Total Org. N Removed in Washes	Residual Org. N, H_2O Added (reconstituted)
			Total N	H_2O Sol. NH_4^+-N	Exch. NH_4^+-N	Org. N		
			(µg N/g)					
Kitchener (4)	$Al_2(SO_4)_3$	8/5/74	3500	1200	167	2133	428	2650
North Toronto (1)	$FeCl_3$	20/11/74	3000	713	80	2207	387	2430
Point Edward (1)	$FeCl_3$	27/11/74	1800	513	25	1262	257	1515
Newmarket (2)	$CaCO_3$	26/11/74	1700	313	30	1357	219	1850
Guelph	$Al_2(SO_4)_3$	28/11/74	1400	550	35	815	124	1820

* fluid basis

TABLE 163. Nitrogen Characterization of Fluid Sludges Used in Experiment 3 and its 6N HCl Hydrolysates.

Sludge	Fluid Sludge		Hydrolysate					Non Hydrolysable N
	Total N	Soluble & Exch. NH_4-N	Total N	NH_4-N	Hexosamine N*	α Amino Acid-N	Unidentified Hydrolysable N	
	µg N/g fluid sludge							
Kitchener	3500	1200	2200	630	46	925	613	100
N. Toronto	3000	710	1760	490	62	920	350	530
Pt. Edward 1974	1800	510	1290	245	37	113	919	0
Newmarket	1700	313	1220	240	36	381	563	167
Guelph	1400	550	670	200	15	275	180	180

* Highest values obtained in 1, 3, and 6 hr. hydrolysis periods used in its estimation.

TABLE 164. Organic Nitrogen Fraction in (Sand + Soil + Sludge) Mixture at Termination of Leaching After 49 Weeks.

Sludge Added to Mixture	Total Kjeldahl N	Total Hydrolizable N	Hydrolysates†				Non Hydrolizable N
			NH_4-N	Hexosamine-N*	α Amino Acid-N	Unidentified	
	mg N/filter						
Kitchener	32.6	27.8	5.0	2.7	10.4	9.7	4.8
N. Toronto	32.1	27.3	5.1	3.3	9.1	9.8	5.1
Pt. Edward '74	30.7	28.2	5.0	2.9	10.6	9.7	2.5
Newmarket	32.7	27.6	5.6	1.8	9.6	10.6	5.1
Guelph	31.4	28.1	4.8	3.1	9.8	10.4	3.4
Control	28.8	22.5	4.4	2.3	8.0	7.8	6.3
Initial Soil	31.5	28.9	5.9	2.6	10.7	8.8	2.6

* Estimated using 1.2 x values obtained by 6 hr hydrolysis.

† 6 hr. hydrolysis in 6N HCl.

TABLE 165. NH_3-N Volatilized from Sludge Applied at the Elora Research Station During the Periods May 8 to 13 and October 8 to 15, 1975.

May 8-13		October 8-15	
Date	Volatilized NH_3-N	Date	Volatilized NH_3-N
	(kg/ha)		(kg/ha)
May 8	17.6*	Oct. 8	13.0**
May 9	29.0	Oct. 9	11.5
May 10	11.5	Oct. 10	3.3
May 11	7.1	Oct. 11	3.6
May 12	4.3	Oct. 12	3.1
May 13	2.7	Oct. 13	1.6
Total	72.2	Oct. 14	2.5
		Oct. 15	1.3
		Total	36.3
Amount of NH_4^+-N applied	150		89
% NH_4^+-N lost as NH_3-N	48		41

* measurements begun at 1 p.m.

**measurements begun at 12 noon.

TABLE 166. NH_4^+-N and NO_3^-N Concentrations in Sludge and Soil Layers and H_2O Content and pH in Soil Layers Following Sludge Application to the Soil Surface at the Elora Research Station During the Period October 7 to November 13, 1975 (Average of 3 Replications).

Sludge or Soil Layer	Oct.7	Oct.8	Oct.9	Oct.10	Oct.12	Oct.14	Oct.16	Oct.23	Oct.30	Nov.5	Nov.13
	% H_2O										
Sludge	-	-	-	-	-	-	-	-	-	-	-
0-2 cm	26.1	36.2	34.1	36.1	34.0	43.5	35.8	34.2	34.5	35.1	38.6
2-4 cm	28.8	34.3	33.7	34.5	33.1	36.8	35.9	33.6	31.9	31.5	34.1
4-10 cm	30.3	32.1	32.8	32.2	30.9	35.6	33.7	33.5	30.9	30.4	34.1
	ppm NO_3^--N										
Sludge *	-	2	3	3	3	4	3	4	4	6	3
0-2 cm	28	45	50	29	33	19	43	49	83	42	66
2-4 cm	19	28	24	31	29	25	27	33	38	38	55
4-10 cm	20	34	40	32	30	26	31	31	39	31	51
	ppm NH_4^+-N										
Sludge *	-	831	923	720	733	661	515	473	635	850	493
0-2 cm	6	8	66	88	73	105	68	44	21	20	14
2-4 cm	7	7	9	11	9	11	12	7	9	8	5
4-10 cm	6	6	7	10	5	5	5	5	3	7	4
	pH										
Sludge	-	-	-	-	-	-	-	-	-	-	-
0-2 cm	7.46	7.68	7.68	7.73	7.66	7.71	7.64	7.40	7.44	7.51	7.11
2-4 cm	7.53	7.69	7.74	7.69	7.66	7.61	7.63	7.49	7.68	7.62	7.32
4-10 cm	7.63	7.69	7.60	7.54	7.61	7.67	7.61	7.47	7.84	7.67	7.28

* The concentrations of NO_3^--N and NH_4^+-N in the sludge layer were not corrected for H_2O content but are presented on an "as sampled" basis.

6. GREENHOUSE STUDIES

6.1 Greenhouse Experiment 1 - comparison of sludges

6.1.1 Objectives

1. To determine the effect of various sewage sludges on crop growth.
2. To determine the effect of metals in sewage sludge on metal uptake by plants.

6.1.2 Materials and methods

The soil used in this study is a Grimsby sandy loam soil (pH 4.6) which was limed to two pH levels, approximately 5.0 and 7.0 using reagent grade $CaCO_3$. The three sewage sludges used in the field trials were applied to these soils along with six other Ontario sludges selected for their high metal content. Sludges were applied at rates supplying 0, 178, 712 and 1424 lb N/ac (0, 200, 800 and 1600 kg N/ha) per application. A total of five crops of ryegrass have been grown and harvested since the experiment was started in 1974. Yield, and nutrient and metal contents of each crop were measured. Nutrient and metal contents of the sludges were also determined. Half of the pots receiving the highest rate of sludge received only one application, and were cropped without further additions. Dates of sludge and fertilizer application, and of seedling and harvest, are shown in Table 167.

6.1.3 Results and discussion

Chemical analyses of sludges applied in the fifth application are presented in Tables 168 and 169. Amounts of nutrients and metals applied in five applications of sludges are presented in Table 170 and amounts added in the fifth application in Tables 171 and 172.

For the fifth crop, the Kitchener sludge was used in place of the Aurora sludge which was not available at that time.

Dry matter yields of the third, fourth and fifth crops of ryegrass are presented in Tables 173, 174, 175, 176 and 177 for each sludge and each rate of nitrogen. Dry matter yields for the five crops of ryegrass averaged across sludges are presented in Table 178. Yields were low in the fifth crop, and this is believed to be chiefly due to the low light intensity in November and December when this crop was grown.

Supplemental light was added for this crop, but was believed to be insufficient in comparison with summer conditions. Some treatments produced low yields in the third crop, and this is believed to have been due to a shortage of nitrogen as the soils were leached after sludge addition to remove excess salts.

Soil pH values after harvest of the fourth crop of ryegrass are presented in Table 179. Sludges from Aurora, Midland, Point Edward and Newmarket largely erased the pH differences established at the beginning of the study. The Midland and Newmarket sludges resulting from calcium hydroxide treatment of sewage added considerable quantities of calcium to the soil (Table 170), so one would expect the high pH values which resulted from their use. The Aurora and Point Edward sludges also supplied appreciable calcium and raised soil pH. However, the Sarnia sludge added more calcium than the Aurora sludge but raised soil pH appreciably less.

Nitrogen concentration in the third, fourth and fifth crops are presented in Tables 180, 181 and 182. Nitrogen concentration increased with sludge application rate, and is believed to have been slightly deficient in the third and fourth crops at the lowest rate of sludge application.

Phosphorus extracted with sodium bicarbonate from the soils after harvest of the fourth crop is presented in Table 183. The two Ca sludges, Midland and Newmarket, have increased extractable soil phosphorus more than the other sludges but there is little relation to amounts of phosphorus added. Phosphorus concentrations in the ryegrass (Tables 184, 185, 186 and 187) were quite high and well above normal crop requirements. Treatment effects were highly significant, but concentrations in the ryegrass do not appear to be closely related to either amounts added in the sludges or amounts extracted from the soil with sodium bicarbonate.

Potassium concentrations (Tables 188, 189, 190 and 191) were quite high in all treatments, but for some reason are lower at the 800 kg N rate from sludge than at lower or higher rates of application.

Calcium concentrations (Tables 192, 193, 194, 195 and 196) were quite high in all treatments.

Magnesium concentrations were rather low in the third crop of ryegrass, probably because of leaching to remove salts, although no deficiency symptoms were apparent. Concentrations in the fourth and fifth crops appeared to be adequate (Tables 197, 198, 199 and 200).

Aluminum concentrations were only affected by treatment in the fourth and fifth crops (Tables 201 and 202). Concentration differences in the ryegrass do not appear to be related to amounts of aluminum added in the different sludges.

Iron concentrations in crops three and five were not affected by treatment. In the fourth crop iron concentration was affected (Table 203) but did not appear to be related to amount of iron applied.

Manganese concentrations in the ryegrass (Tables 204, 205, 206, 207, 208 and 209) varied widely among treatments, and in general appeared to be related to soil pH (Table 179), the calcium sludges, Midland and Newmarket, producing low manganese concentrations, and the Fergus and North Toronto sludges producing quite high manganese concentrations particularly on the low pH treatment. Some of the higher levels are probably approaching toxicity.

Boron concentrations in the ryegrass did not vary greatly but treatment effects were significant in the fifth crop (Table 210). The Midland sludge which supplied the most boron produced the highest boron concentration in the ryegrass.

Cadmium concentrations in the third and fifth crops of ryegrass are presented in Tables 211, 212 and 213. Cadmium concentrations in the fourth crop were not significantly affected by treatment. Concentration in the ryegrass was related to rate of sludge application, but there was not a very close relation between cadmium concentration and amount applied when different sludges are compared. Cadmium concentration in all five crops of ryegrass resulting from Guelph sludge applications are presented in Table 214. Guelph sludge was presented here as it resulted in the highest cadmium concentration in the ryegrass. There was little or no tendency for metal concentrations in the ryegrass to increase from one crop to the next even with repeated applications of high rates of sludge containing appreciable cadmium.

Copper concentrations in ryegrass from the third, fourth and fifth crops are presented in Tables 215, 216, 217, 218, 219 and 220. Copper concentrations in all five crops of ryegrass resulting from application of the Fergus sludge are presented in Table 221. Yield was seriously depressed at the higher rates of Fergus sludge (Tables 178 and 222), and this is believed to be due to copper toxicity. The Guelph sludge supplied nearly as much copper as the Fergus sludge (Table 170) but resulted in much lower copper concentrations in the ryegrass (Tables 215 and 220).

Chromium concentrations in the fifth crop of ryegrass are presented in Table 223. In general chromium concentrations were rather uniform and low.

Nickel concentrations in the third, fourth and fifth crops of ryegrass are presented in Tables 224, 225, 226, 227 and 228, and for all five crops of ryegrass in Table 229. Nickel concentrations were markedly affected by both source and rate of sludge and by soil pH. The Midland sludge provided by far the largest quantities of nickel and produced the highest concentrations in ryegrass. Concentrations in all five crops of ryegrass with the Midland sludge are presented in Table 230. Nickel did not appear to be toxic to the ryegrass crop even at these elevated concentrations.

Lead concentrations in ryegrass (Table 231) were affected by sludge source in the third and fifth crops, and there was a tendency for the concentrations in ryegrass to be related to the amounts added in the different sludges.

Zinc concentrations in the third, fourth and fifth crops of ryegrass are presented in Tables 232, 233, 234 and 235. Zinc concentrations in all five crops of ryegrass, but averaged across sludges, are presented in Table 236. Zinc concentration was markedly affected by source and rate of sludge and by soil pH. The Fergus sludge produced the highest zinc concentration in the ryegrass, although it did not add nearly as much zinc to the soil as the Sarnia sludge. Zinc concentration in the ryegrass increased with increasing rate of sludge application at any one time, but did not increase from crop to crop even when large amounts of zinc were added in the sludge for each crop.

Molybdenum concentration was determined in the third, fourth and fifth crops of ryegrass on selected treatments (Table 237). Sludge application increased the molybdenum concentration in the forage in all three crops.

Mercury concentration was determined on selected treatments in the third, fourth and fifth crops of ryegrass (Table 238), but does not appear to have been affected by treatment.

Selenium concentration was determined on selected treatments in the third, fourth and fifth crops of ryegrass (Table 239), but does not appear to have been affected by treatments.

6.1.4 Conclusions

Increased rates of application of sewage sludge applied at one time increased the concentration of metals in the ryegrass. However, repeated cycles of sludge application and cropping did not increase concentrations of metals in the ryegrass from one crop to the next at any of the rates studied.

Sludge applied only once produced Ni concentrations in the first three crops of ryegrass that were as high as a treatment receiving three applications of the same amount of sludge (one application before each crop). Differences were noticeable in the fourth crop and for Cd and Cu in most crops after the first. The pattern with Zn was intermediate between those with Cd and Ni. If metals remained plant-available for only a few weeks after each application, this would explain these results. However, if availability were to drop rapidly after application, the metal concentration in ryegrass receiving only one application of sludge at the 1600 kg N/ha rate should have been very low in the second, third, fourth and fifth crops, much lower than in the treatment receiving repeated applications of sludge at the 1600 kg N/ha rates. This did not occur with any of the metals. The reasons for the lack of increase in metal concentration from one crop to the next, as metal addition continued with repeated sludge application, is not known.

6.2 Greenhouse Experiment II - selection of extractant

6.2.1 Objectives

To develop or find suitable measures of plant-available metals in Ontario soils.

6.2.2 Preamble

The approach taken in this study was to search for an extractant which removes that fraction of metals from a representative group of Ontario soils that is highly correlated with the amount of metals removed from the same soils by plants. A number of extractants have been proposed. Haq and Miller (1972) found DTPA and EDTA to be satisfactory for zinc in Ontario soils when pH was also included in a prediction equation. It has frequently been suggested that these two extractants are suitable for other metals, but Haq and Miller found them unsatisfactory for copper. The several other extractants which have been suggested for plant-available metals have not been tested under Ontario conditions and in most cases have not been tested on a range of soils. In most cases they have been tested as measures of availability of metals added at the beginning of an experiment. Any extractant which is to serve as a useful measure of available metals under Ontario conditions must function on a range of soils and with metals which have been added recently or over a period of years.

6.2.3 Plan of research

A greenhouse experiment was conducted on 46 surface soil materials collected mostly from various sites in southern Ontario but with two from the Sudbury region of northern Ontario. These soils were believed to be contaminated with heavy metals over a period of years and to varying degrees by the application of sewage sludges and insecticides, from dumping snow from city streets and from air pollution around metal smelters. Since some of the samples were collected from virgin sites, a crop of ryegrass was grown in all the soils for five weeks before starting the actual experiment. After the harvest of ryegrass the soils were dried at room temperature and sieved through a 2 mm stainless steel screen. Reagent grade $Ca(H_2PO_4)_2$ and KCl were added to each soil at rates believed from soil analysis to be adequate for crop production.

A portion of each soil was then saved for chemical analysis. Nitrogen as $(NH_4)_2SO_4$ was added at seeding and in three weekly applications each of 25 µg/g of soil. Swiss chard was grown as it is believed to be a good accumulator of heavy metals. Ten seeds were placed in each plastic pot containing 2 kg soil on an air-dry basis. White silica sand was spread over the surface at the rate of 500 g/pot. Two replicates (two pots) of each soil were used in a completely randomized design. Pots were rotated in the greenhouse on alternate days to minimize the effect of any environmental differences. Plants were thinned to five per pot three days after emergence. Pots were watered to one-third bar tension by weight with deionized water daily or more often if required. Temperature in the greenhouse followed a diurnal sinosoidal pattern ranging from a minimum of 18°C at night to 24°C maximum in the daytime. The Swiss chard leaves were harvested at 40 days, washed with 0.1% solution of "Agral 90" detergent, dried at 65°C for 36 hours and ground in a stainless steel Wiley mill. The plant material was ashed in a muffle furnace at 450°C, the ash dissolved in 3 ml of aqua regia and diluted to 10 ml with distilled water and analyzed by atomic adsorption for Cd, Cu, Ni, Pb and Zn.

The values obtained for Ni and Cd were corrected by subtracting the background absorption as suggested by Van Loon and Lichwa (1973). The various soil extractants tested are listed below:

(i) Aqua Regia (HNO_3 + HCl)
Soil to extractant ratio was 1:12 with 30 minute digestion at 110 - 120°C on a hot plate. Filtered through Whatman No. 42 filter paper and diluted to 25 ml with distilled water (Van Loon and Lichwa).

(ii) Ammonium acetate (1 N, pH 7.0)
Soil to extractant ratio was 1:10 with 30 minute shaking period. The suspension was filtered through Whatman No. 42 filter. (John, M.K. et. al., 1972).

(iii) 0.5 N - Acetic acid
Procedure otherwise identical to ammonium acetate.

(iv) EDTA* (0.01M EDTA in 1M $(NH_4)_2CO_3$, pH 8.6)
Soil to extractant ratio was 1:2 with a 30 minute shaking period. (Trierweiler and Lindsay, 1969).

(v) DTPA*
The extractant contained 0.05M DTPA, 0.1M TEA and 0.01M $CaCl_2$ at pH 7.3. The soil to extractant ratio was 1:2 and shaking time two hours. (Lindsay, 1972).

(vi) NTA* (25mM NTA in 25mM sodium citrate, pH 6.0)
Soil to extractant ratio was 1:5 with one hour shaking period.[1]

(vii) 0.5 N HCl + 0.05 N $AlCl_3$
Soil to extractant ratio of 1:5 with five minute shaking period. (Mehlich and Bowling, 1975).

(viii) Oxalic acid + ammonium oxalate
25 g ammonium oxalate and 12.6 g oxalic acid dissolved in one litre of distilled water. Soil to extractant ratio was 1:10 with overnight shaking period. (Grigg, J.L., 1953).

(ix) Water
100 g soil were shaken for four hours with 200 ml distilled water and filtered through Sartorius membrane filter with 0.45 μ pore size. The extract was concentrated using APDC (Ammonium 1 - Pyrrolidine dithiocarbamate) in MIBK (Methyl isobutyl Ketone) as outlined by Parker (1972).

A stepwise regression program (Draper and Smith, 1968) was used to develop multiple regression equations for each extractant describing concentration of a single metal in Swiss chard as a function of extractable soil metal, soil pH, % clay, % O.M. and cation exchange capacity. All

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[1] Soon, Y.K. 1975. Unpublished, University of Guelph, Ontario, Canada.

*Abbreviations

EDTA: Ethylenediaminetetraacetic acid
DPTA: Diethylenetriaminepentaacetic acid
NTA: Nitrilotriacetic acid
TEA: Triethanolamine

first order interactions among these variables and the square of each variable were also included in the programme as possible variables in the equation. Only those variables which contributed significantly at the 0.05 probability by F test are included in the equations presented.

6.2.4 Results and discussion

The characteristics of soils used in greenhouse experiment II are presented in Table 240, and appear to cover the range of agriculturally important soils in the province rather well, with the one exception that they do not provide any representation of organic soils. Aqua regia extractable metal content of these soils is presented in Table 241 and compared with levels in agricultural soils in Ontario. The metal concentrations in the soils are in general well above those occurring in agricultural soils across the province. Metal concentrations in the Swiss chard leaves are presented in Table 242. With the exception of lead there is an appreciable range in metal concentration in the Swiss chard plants.

Cadmium: All extractants removed amounts of Cd from the soils which correlated significantly with Cd concentration in Swiss chard. Soil pH improved the prediction of Cd concentration in the Swiss chard for most extractants (Table 243) with soil organic matter, clay content and cation exchange capacity improving the correlation in a number of cases.

The equation which explains the greatest portion of the variability in Cd concentration is that with HCl + $AlCl_3$ (93%), but this would require measurement of soil pH, clay content and organic matter as well as extractable Cd. The NTA equation explains 90% of the variability in Cd concentration using extractable Cd, soil organic matter and pH, and is probably more useful than HCl + $AlCl_3$ because clay content does not have to be measured.

Copper: Although equations were developed which explained up to 82% of the variability in Cu concentration in Swiss chard, most of these equations did not include extractable Cu as a significant variable (Table 244). Zinc was a significant variable in a number of the equations. However, two equations did show extractable Cu to be the most important single factor in predicting plant Cu concentrations (equations with NTA and HCl + $AlCl_3$), but these equations were less effective in predicting Cu concentration than other equations which did not include Cu but included Zn extracted with DTPA, EDTA, CH_3COONH_4 or CH_3COOH. Attempts to find an extractant which measures plant available Cu directly have thus far failed.

Nickel: Equations developed with six of the extractants were all quite effective in predicting Ni concentration in Swiss chard, explaining from 88 to 97% of the variability (Table 245). Ni extracted by NTA explained 82% of the variability without measurement of any other variable. Where organic matter and clay content were also measured, 95% of the variability in Ni concentration was explained. HCl + $AlCl_3$ explained 95% of the variability where organic matter and cation exchange capacity were measured. EDTA and DTPA can also be used to predict Ni concentration provided other soil variables are measured.

Lead: A number of extractants removed amounts of Pb which correlated significantly with Pb concentration in Swiss chard. However, even when a number of other variables were included in the equations only 64% of the variability in Pb concentration in Swiss chard could be explained (with aqua regia) (Table 246). It may be that the low predictability of Pb concentration in the Swiss chard is due to the rather narrow range of Pb values in the Swiss chard.

Zinc: Zinc was one of the more predictable elements, Zn extracted by CH_3COONH_4 alone explaining 85% of the variability in Zn concentration in Swiss chard (Table 247). Where soil pH was also included, CH_3COONH_4-extractable zinc explained 91% of the variability. When clay content and pH are both measured EDTA, HCl + $AlCl_3$ and NTA all explain over 90% of the variability in Zn concentration.

6.2.5 Conclusions

Several extractants could be used to predict Cd, Ni and Zn concentrations in Swiss chard and the predictions were improved in most cases where pH, clay content, organic matter and cation exchange capacity were also measured. NTA is probably the most universally acceptable extractant for all three of these metals on the group of soils studied. At this stage satisfactory extractants for Cu and Pb have not been found.

6.2.6 Literature cited

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TABLE 167. Calendar of Operations in Greenhouse Experiment 1 (Ryegrass).

Treatment	1st crop	2nd crop	3rd crop	4th crop	5th crop
	Fertilizer added to check pots				
Potassium chloride	-	-	54 lb K_2O/ac (50 kg K/ha)	-	54 lb K_2O/ac* (50 kg K/ha)
Magnesium sulphate	18 lb Mg/ac (20 kg Mg/ha)	-	45 lb Mg/ac (50 kg Mg/ha)	-	45 lb Mg/ac* (50 kg Mg/ha)
Ammonium nitrate	178 lb N/ac (200 kg N/ha)	178 lb N/ac (200 kg N/ha)	178 lb N/ac (200 kg N/ha)	178 lb N/ac (200 kg N/ha)	178 lb N/ac** (200 kg N/ha)
Triple superphosphate	54 lb P_2O_5/ac (50 kg P_2O_5/ha)	-	-		-
Sludge application completed	February 27, 1974	June 11, 1974	January 23, 1975	May 23, 1974	September 25, 1975
Date Seeded	March 14, 1974	September 5, 1974	March 21, 1975	June 6, 1975	November 13, 1975
Date harvested	April 23, 1974	October 11, 1974	April 25, 1975	July 14, 1975	December 24, 1975
Leaching to remove salts	-	-	yes†	-	yes†

* added to all treatments.

** added to those treatments which received sludge once only.

† pots were leached to remove salts after sludge application but before seeding the ryegrass.

TABLE 168. Concentration of Various Constituents in Fifth Application of Nine Ontario Fluid Sewage Sludges Used in 1975 Greenhouse Experiment.

Sludge	pH	D.M.	N	Soluble & Exch. NH_4-N	P	K	Ca	Mg	Na	Al	Fe
	------	------	------	------	------	%	------	------	------	------	------
Kitchener	7.4	3.5	.23	0.121	.10	.02	.33	.03	0.028	0.018	0.012
Midland	7.2	9.2	.11	0.023	.21	.01	2.23	.07	0.032	0.041	0.048
Point Edward	7.2	5.3	.17	0.056	.21	.02	.28	.03	0.012	0.018	0.344
Sarnia	7.1	8.6	.22	0.051	.18	.04	.33	.08	0.018	0.090	0.398
Guelph	7.1	3.3	.14	0.051	.10	.02	.22	.03	0.024	0.067	0.065
Fergus	7.4	4.1	.23	0.107	.16	.01	.24	.05	0.034	0.014	0.201
North Toronto	7.3	5.3	.24	0.097	.24	.02	.22	.03	0.018	0.047	0.234
Newmarket	7.2	3.5	.13	0.048	.08	.01	.62	.03	0.018	0.007	0.072
Toronto Humber	7.1	3.5	.16	0.053	.08	.02	.20	.02	0.017	0.026	0.031

TABLE 169. Metal Concentration in Fifth Application of Nine Ontario Fluid Sewage Sludges Used in 1975 Greenhouse Experiment.

Sludge	B	Mo	Mn	Cd	Cr	Cu	Ni	Pb	Zn	Hg	Se
	------------------------------					μg/g					------------------------------
Kitchener	1.9	0.56	8.6	0.49	252	19	8.2	13	145	0.052	<.001
Midland	3.7	1.15	28.8	0.51	28	33	102	56	104	0.496	0.067
Point Edward	0.6	0.93	16.4	0.43	18	37	2.3	24	37	0.118	<.001
Sarnia	0.9	1.18	214	7.75	15	51	3.4	300	856	0.189	<.001
Guelph	1.0	2.16	7.3	15.0	60	76	2.5	34	158	0.103	0.002
Fergus	0.7	0.62	9.0	0.53	58	171	7.0	13	565	0.105	0.002
North Toronto	0.5	1.71	22.9	1.47	26	51	1.6	74	105	0.589	<.001
Newmarket	1.1	0.53	14.5	0.28	3.4	14.5	1.4	16	76	0.064	<.001
Toronto Humber	0.6	1.17	9.5	2.31	67	37	13.1	57	95	0.093	0.003

TABLE 170. Total Amounts of Nutrients and Metals Applied in the First Five Applications of Sludges at 200 kg N/ha Per Application.

	Aurora*	Midland	Pt. Edward	Sarnia	Guelph	Fergus	N. Toronto	Newmarket	Tor. Humber
					kg/ha				
Solids	23,100	80,660	39,680	36,740	24,960	17,470	21,430	55,120	18,750
Soluble & exch. NH_4-N	301	176	265	340	399	462	338	337	414
P	556	2517	1547	934	1258	484	949	731	521
K	66	119	100	164	77	61	77	89	94
Ca	1537	17,595	2990	1665	1393	1026	900	14,170	1070
Mg	162	747	295	426	242	233	141	315	150
Na	89	142	53	51	129	211	54	104	71
Al	1815	891	136	209	473	63	248	198	205
Fe	161	679	3713	2719	615	826	1578	1114	511
Mn	7.4	23	15	79	5.5	4.4	8.6	20	6.1
Cd	0.15	0.51	0.29	3.0	6.4	0.49	0.68	0.19	2.4
Cr	188	58	4.4	4.8	81	45	11.5	1.8	66
Cu	11	32	30	30	71	89	29	13	28
Ni	4.3	210	1.2	1.2	2.3	3.0	0.73	1.1	9.3
Pb	6.7	51	24	126	31	8.2	40	9.7	46
Zn	22	98	33	400	153	216	60	43	119
B	2.3	4.4	1.2	1.1	1.0	0.76	0.64	1.2	0.68
Hg	0.045	0.52	0.094	0.20	0.20	0.049	0.41	0.13	0.14
Mo	0.25	0.81	0.31	0.51	1.7	0.15	0.54	0.28	1.05
Se	0.8	0.5	0.001	0.001	1.1	0.008	0.01	0.5	0.7

* Kitchener sludge was substituted for the fifth crop.

TABLE 171. Total Amounts of Various Constituents Added in Fifth Application of Sludge at 200 kg N/ha to Greenhouse Experiment.

Sludge	Solids	Soluble & Exch. NH_4-N	P	K	Ca	Mg	Na	Al	Fe	Mn
						kg/ha				
Kitchener	3,043	105	87	17.4	287	26	24	15.7	10.4	0.75
Midland	16,727	42	382	18.2	4055	127	58	75	87	5.2
Point Edward	6,235	66	247	23.5	329	35	14	21	405	1.9
Sarnia	7,818	46	164	36.4	300	73	16	82	362	19.5
Guelph	4,714	73	143	28.6	314	43	34	96	93	1.0
Fergus	3,565	93	139	8.7	209	43	30	12	175	0.78
N. Toronto	4,417	81	200	16.7	183	25	15	39	195	1.9
Newmarket	5,385	74	123	15.4	954	46	28	11	111	2.2
Toronto Humber	4,375	66	100	25	250	25	21	33	39	1.2

TABLE 172. Total Amounts of Trace Elements and Metals Added in Fifth Application of Sludge at 200 kg N/ha to Greenhouse Experiment.

Sludge	Cd	Cr	Cu	Ni	Pb	Zn	B	Hg	Mo	Se
						kg/ha				
Kitchener	0.042	21.9	1.65	0.71	1.13	12.6	0.17	0.005	0.05	<0.001
Midland	0.093	5.1	6.0	18.5	10.2	18.9	0.67	0.090	0.21	0.012
Point Edward	0.051	2.1	4.4	0.27	2.8	4.4	0.07	0.014	0.11	<0.001
Sarnia	0.705	1.4	4.6	0.31	27.3	77.8	0.08	0.017	0.11	<0.001
Guelph	2.14	8.6	10.9	0.36	4.9	22.6	0.14	0.015	0.31	<0.001
Fergus	0.046	5.0	14.9	0.61	1.13	49.1	0.06	0.009	0.05	<0.001
N. Toronto	0.122	2.2	4.2	0.13	6.2	8.7	0.04	0.049	0.14	<0.001
Newmarket	0.043	0.5	2.23	0.22	2.5	11.7	0.17	0.010	0.08	<0.001
Toronto Humber	0.289	8.4	4.6	1.64	7.1	11.9	0.08	0.012	0.15	<0.001

TABLE 173. Dry Matter Yield to Third Crop of Ryegrass at Two Soil pH Values. Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (Kg/ha)									
	pH 5.0					pH 7.0				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN
					g/pot					
None					7.8					8.2
Aurora	4.5	7.1	7.7	1.4	5.2	3.8	6.4	7.1	2.3	4.9
Midland	2.4	6.5	6.6	3.4	4.7	2.4	6.4	6.2	3.1	4.5
Point Edward	2.4	3.0	4.2	2.3	3.0	2.1	2.7	5.5	1.4	2.9
Sarnia	2.5	5.1	5.6	3.6	4.2	2.6	4.4	5.5	3.9	4.1
Guelph	3.9	6.0	6.4	5.0	5.3	4.7	6.1	6.6	2.0	4.9
Fergus	5.6	3.2	1.2	7.0	4.0	4.8	5.7	3.5	4.1	4.5
N. Toronto	2.9	5.9	8.8	3.8	5.4	2.9	6.7	7.7	2.9	5.0
Newmarket	4.0	6.1	7.1	3.4	5.2	2.9	5.9	7.1	3.4	4.8
Toronto Humber	5.2	5.5	7.6	6.5	6.2	3.5	6.2	8.0	2.5	5.1
Mean	3.7	5.4	6.1	4.1	4.8	3.3	5.6	6.4	2.8	4.5

*Sludge applied only once.

Significance of "F" test at 0.05 and 0.01 probability			
sludge source	.01	source x rate	.01
sludge rate	.01	source x soil pH	.01
soil pH	.01	soil pH x rate	.01
		source x rate x soil pH	.01

TABLE 174. Dry Matter Yield of Ryegrass Averaged Over Two Soil pH Values. Third Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
			g/pot		
None					8.0
Aurora	4.2	6.8	7.4	1.9	5.1
Midland	2.4	6.4	6.4	3.2	4.6
Point Edward	2.2	2.8	4.8	1.9	2.9
Sarnia	2.5	4.8	5.5	3.7	4.1
Guelph	4.3	6.1	6.5	3.5	5.1
Fergus	5.2	4.5	2.3	5.6	4.4
N. Toronto	2.9	6.3	8.3	3.3	5.2
Newmarket	3.4	6.0	7.1	3.4	5.0
Toronto Humber	4.4	5.9	7.8	4.5	5.6
Mean	3.5	5.5	6.2	3.4	4.7

* Sludge applied only once.

Significance of "F" test at 0.05 and 0.01 probability

sludge source - .01
sludge rate - .01
soil pH - .01

source x rate - .01
source x soil pH - .01
soil pH x rate - .01
source x rate x soil pH - .01

TABLE 175. Dry Matter Yield of Fourth Crop of Ryegrass Averaged Over Two Soil pH Values. Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
			g/pot		
None					9.7
Aurora	10.5	8.2	10.3	5.9	8.7
Midland	6.3	7.1	8.9	6.6	7.2
Point Edward	6.3	8.1	7.4	6.9	7.2
Sarnia	5.9	10.2	8.8	6.7	7.9
Guelph	5.9	9.6	7.9	6.3	7.5
Fergus	6.8	6.1	1.5	7.3	5.4
N. Toronto	5.4	7.8	6.2	6.2	6.4
Newmarket	5.9	8.8	10.0	6.8	7.9
Toronto Humber	8.3	9.5	12.3	5.6	8.9
Mean	6.8	8.4	8.1	6.5	7.5

* Applied only once.

Significance of "F" test at 0.05 and 0.01 probability

sludge source - .01
sludge rate - .01
soil pH - N.S.

source x rate - .01
source x soil pH - N.S.
soil pH x rate - N.S.
source x rate x soil pH - N.S.

TABLE 176. Dry Matter Yield of Ryegrass, Fifth Crop, Greenhouse Experiment, 1975.

Sludge	Original Soil pH									
	5.0					7.0				
	Nitrogen Rate (kg/ha)					Nitrogen Rate (kg/ha)				
	200	800	1600	1600*	Mean	200	800	1600	1600*	Mean
	g/pot									
None					4.5					5.6
Aurora	4.0	3.8	4.9	5.7	4.6	4.8	4.9	5.0	5.4	5.0
Midland	4.8	5.1	4.4	3.2	4.4	4.4	4.8	4.5	4.9	4.7
Point Edward	3.6	3.9	4.0	4.3	3.9	3.9	3.8	2.9	5.0	3.9
Sarnia	3.4	4.9	5.2	4.2	4.4	4.4	4.7	4.0	4.8	4.5
Guelph	3.9	3.9	5.4	4.4	4.4	4.7	3.9	4.2	5.5	4.6
Fergus	4.0	2.5	2.5	2.6	2.9	4.5	4.2	1.7	6.4	4.2
North Toronto	4.2	5.0	4.7	4.0	4.5	4.5	4.5	5.0	4.7	4.7
Newmarket	3.8	4.5	4.7	5.4	4.6	3.8	4.8	5.4	3.8	4.5
Toronto Humber	4.3	4.1	4.5	5.1	4.5	4.6	4.8	4.4	5.7	4.9

* Sludge applied only once.

Significance of "F" test at 0.05 and 0.01 probability.

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.01
source x rate - 0.01
soil pH x rate - 0.01
soil pH x source - n.s.

TABLE 177. Dry Matter Yield of Ryegrass Averaged Over Two Soil pH Values. Fifth Crop, Greenhouse Experiment, 1975.

Sludge	Nitrogen Rate lb/ac (kg/ha)				Mean
	178 (200)	712 (800)	1424 (1600)	1424 (1600)*	
			g/pot		
None					5.1
Aurora	4.4	4.3	5.0	5.5	4.8
Midland	4.6	4.9	4.4	4.1	4.5
Point Edward	3.7	3.8	3.5	4.7	3.9
Sarnia	3.9	4.8	4.6	4.5	4.5
Guelph	4.3	3.9	4.8	5.0	4.5
Fergus	4.3	3.4	2.1	4.5	3.5
N. Toronto	4.4	4.8	4.9	4.3	4.6
Newmarket	3.8	4.7	5.1	4.6	4.5
Toronto Humber	4.4	4.5	4.4	5.4	4.7
Mean	4.2	4.3	4.3	4.7	4.4
pH 5.0	4.0	4.2	4.5	4.3	4.2
7.0	4.4	4.5	4.1	5.1	4.5

* One application only.

Significance of "F" test at 0.05 and 0.01 probability.

sludge source	- 0.01	source x rate	- 0.01
sludge rate	- 0.01	soil pH x rate	- 0.01
soil pH	- 0.01	soil pH x source	- n.s.

TABLE 178. Dry Matter Yields of Five Crops of Ryegrass Averaged Across Nine Sludges.

Crop	Original Soil pH	Source and Rate of Nitrogen - lb/ac (kg/ha)				
		NH_4NO_3	Sewage Sludge			
		178 (200)	178 (200)	712 (800)	1424 (1600)	1424* (1600)
				g/pot		
First	5.0	6.0	8.5	9.8	8.9	8.6
	7.0	9.6	10.3	10.5	10.4	9.8
Second	5.0	7.6	7.6	6.5	4.1	5.1
	7.0	7.3	7.1	5.3	3.7	5.1
Third	5.0	7.8	3.7	5.4	6.1	4.0
	7.0	8.2	3.3	5.6	6.3	2.8
Fourth	5.0	9.2	6.7	8.4	8.0	6.3
	7.0	10.2	6.9	8.4	8.3	6.5
Fifth	5.0	4.5	4.0	4.2	4.5	4.3
	7.0	5.6	4.5	4.1	5.1	4.5

* Applied once only.

TABLE 179. Soil pH After Harvest of the Fourth Crop of Ryegrass.

Sewage Sludge	Original Soil pH					
	5.0			7.0		
	Nitrogen Rate - kg/ha					
	200	1600	1600*	200	1600	1600*
None	5.0			6.5		
Aurora	6.3	7.3	6.6	7.4	7.6	7.5
Midland	7.9	8.1	7.3	8.1	8.2	7.4
Point Edward	6.4	7.3	6.7	7.1	7.2	7.4
Sarnia	5.9	6.5	6.0	6.6	6.6	6.6
Guelph	5.7	6.3	5.8	6.7	6.6	6.6
Fergus	5.4	5.2	5.4	6.7	5.5	6.0
N. Toronto	5.4	5.1	5.3	6.4	5.1	6.2
Newmarket	7.8	8.1	8.1	8.0	8.2	8.1
Toronto Humber	5.6	5.6	5.1	6.6	6.0	6.7

* Sludge applied only once.

TABLE 180. Nitrogen Concentration in Ryegrass Averaged Over Two Soil pH Values. Third Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
			% N		
None					2.87
Aurora	2.18	3.06	4.69	5.04	3.74
Midland	2.02	3.21	4.02	4.71	3.49
Point Edward	2.16	2.57	2.66	4.76	3.04
Sarnia	1.87	2.49	2.95	4.30	2.90
Guelph	2.45	3.24	2.50	4.42	3.15
Fergus	2.22	3.85	4.07	4.57	3.65
N. Toronto	2.24	3.85	3.47	4.69	3.56
Newmarket	2.54	3.67	2.97	4.89	3.52
Toronto Humber	2.32	3.61	3.82	4.84	3.65
Mean	2.22	3.28	3.46	4.69	3.41

*Sludge applied only once.

Significance of "F" test at 0.05 and 0.01 probability

sludge source	- 0.01	source x rate	- 0.01
sludge rate	- 0.01	source x soil pH	- N.S.
soil pH	- N.S.	soil pH x rate	- N.S.
		source x rate x soil pH	- N.S.

TABLE 181. Nitrogen Concentration in Ryegrass Averaged Over Two Soil pH Values. Fourth Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
			% N		
None					3.41
Aurora	2.43	4.86	4.75	2.58	3.65
Midland	2.00	4.31	4.89	2.46	3.42
Point Edward	1.86	3.86	4.04	2.98	3.18
Sarnia	1.98	4.40	4.86	2.43	3.42
Guelph	1.83	3.63	4.43	2.05	2.98
Fergus	1.99	4.30	4.18	2.13	3.15
N. Toronto	1.99	4.70	4.70	2.05	3.36
Newmarket	2.01	3.80	4.40	2.09	3.08
Toronto Humber	2.40	4.46	4.31	1.99	3.29
Mean	2.05	4.26	4.51	2.30	3.28

* Applied only once.

Significance of "F" test at 0.05 and 0.01 probability

sludge source - .01
sludge rate - .01
soil pH - N.S.

source x rate - .01
source x soil pH - N.S.
soil pH x rate - N.S.
source x rate x soil pH - N.S.

TABLE 182. Nitrogen Concentration in Ryegrass Averaged Over Two Soil pH Values. Fifth Crop, Greenhouse Experiment, 1975.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424 (1600)*	Mean
		% N			
None					5.00
Aurora	4.48	4.78	4.75	5.45	4.86
Midland	2.78	3.80	5.40	5.58	4.39
Point Edward	2.35	2.83	4.43	5.43	3.76
Sarnia	1.83	4.18	4.73	4.98	3.93
Guelph	3.20	2.50	4.20	5.33	3.81
Fergus	2.53	4.05	4.00	4.75	3.83
N. Toronto	2.50	4.25	4.08	5.55	4.09
Newmarket	4.30	4.40	5.30	5.35	4.84
Toronto Humber	2.60	3.58	4.78	5.23	4.04
Mean	2.95	3.82	4.63	5.29	4.17

* One application only.

Significance of "F" test at 0.05 and 0.01 probability.

sludge source - 0.01
sludge rate - 0.01
soil pH - n.s.
source x rate - 0.01
soil pH x rate - 0.05
soil pH x source - n.s.

TABLE 183. Sodium Bicarbonate-extractable Soil Phosphorus Measured After Harvest of the Fourth Crop of Ryegrass.

Sewage Sludge	Original Soil pH							
	5.0				7.0			
	Nitrogen Rate - kg/ha							
	200	800	1600	1600*	200	800	1600	1600*
	μg P/g soil							
None	150				105			
Aurora	85	80	80	80	85	90	90	90
Midland	335	580	950	185	405	800	1200	310
Point Edward	110	125	175	125	125	165	180	140
Sarnia	100	110	110	105	100	115	115	115
Guelph	150	135	130	165	130	115	120	135
Fergus	135	130	105	130	100	120	125	105
N. Toronto	120	135	140	145	105	120	145	125
Newmarket	315	360	475	305	255	440	450	300
Toronto Humber	140	135	110	130	95	115	115	115

* Sludge applied once only.

TABLE 184. Phosphorus Concentration in Ryegrass Averaged Over Two Soil pH Values. Third Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
			% P		
None					0.60
Aurora	0.66	0.53	0.51	0.89	0.65
Midland	0.81	0.64	0.53	0.92	0.73
Point Edward	0.90	0.97	0.80	0.88	0.89
Sarnia	0.84	0.80	0.79	0.97	0.85
Guelph	0.82	0.75	0.77	0.99	0.83
Fergus	0.67	0.53	0.49	0.85	0.63
N. Toronto	0.84	0.74	0.76	0.93	0.82
Newmarket	0.66	0.58	0.57	0.84	0.66
Toronto Humber	0.81	0.77	0.70	0.94	0.81
Mean	0.78	0.70	0.66	0.91	0.76

* Sludge applied only once.

Significance of "F" test at 0.05 and 0.01 probability

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.05

source x rate - 0.01
source x soil pH - 0.05
soil pH x rate - 0.05
source x rate x soil pH - 0.01

TABLE 185. Phosphorus Concentration in Ryegrass at Two Soil pH Values. Third Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)									
	pH 5.0					pH 7.0				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN
					% P					
None					0.62					0.59
Aurora	0.58	0.55	0.47	0.88	0.62	0.73	0.51	0.54	0.89	0.67
Midland	0.90	0.64	0.52	0.95	0.75	0.72	0.64	0.54	0.90	0.70
Point Edward	0.95	0.94	0.92	0.84	0.91	0.84	1.00	0.68	0.92	0.86
Sarnia	0.83	0.74	0.73	0.98	0.82	0.85	0.87	0.84	0.96	0.88
Guelph	0.88	0.68	0.74	0.91	0.80	0.75	0.82	0.81	1.07	0.86
Fergus	0.71	0.42	0.43	0.77	0.58	0.62	0.64	0.55	0.92	0.68
N. Toronto	0.80	0.75	0.76	0.94	0.81	0.88	0.73	0.75	0.92	0.82
Newmarket	0.67	0.57	0.57	0.86	0.67	0.64	0.58	0.56	0.81	0.65
Toronto Humber	0.73	0.71	0.75	0.93	0.78	0.90	0.83	0.66	0.95	0.83
Mean	0.78	0.67	0.66	0.89	0.75	0.77	0.74	0.66	0.93	0.77

*Applied once only

Significance of "F" test at 0.05 and 0.01 probability

Sludge Source	.01	source x rate	.01
sludge rate	.01	source x soil pH	.05
soil pH	.05	soil pH x rate	.05
		source x rate x soil pH	.01

TABLE 186. Phosphorus Concentration in Ryegrass Averaged Over Two Soil pH Values. Fourth Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
			% P		
None					0.57
Aurora	0.52	0.52	0.46	0.58	0.52
Midland	0.60	0.54	0.58	0.64	0.59
Point Edward	0.63	0.54	0.56	0.55	0.57
Sarnia	0.72	0.61	0.58	0.66	0.64
Guelph	0.66	0.71	0.68	0.73	0.69
Fergus	0.59	0.49	0.38	0.57	0.51
N. Toronto	0.65	0.73	0.71	0.68	0.69
Newmarket	0.55	0.60	0.52	0.49	0.54
Toronto Humber	0.68	0.65	0.75	0.67	0.69
Mean	0.62	0.60	0.58	0.62	0.60

* One application of sludge only.

Significance of "F" test at 0.05 and 0.01 probability

sludge source - 0.01
sludge rate - 0.05
soil pH - N.S.

source x rate - 0.01
source x soil pH - N.S.
soil pH x rate - N.S.
source x rate x soil pH - N.S.

TABLE 187. Phosphorus Concentration in Ryegrass. Fifth Crop, Greenhouse Experiment, 1975.

Sludge	Original Soil pH		Nitrogen Rate lb/ac (kg/ha)				
	5.0	7.0	178 (200)	712 (800)	1424 (1600)	1424 (1600)*	Mean
			% P				
None	0.40[†]	0.55					0.48
Aurora	0.50	0.56	0.60[§]	0.55	0.50	0.48	0.53
Midland	0.61	0.59	0.60	0.55	0.58	0.68	0.60
Point Edward	0.61	0.63	0.63	0.65	0.65	0.58	0.62
Sarnia	0.66	0.70	0.65	0.73	0.68	0.68	0.68
Guelph	0.73	0.73	0.73	0.80	0.73	0.65	0.73
Fergus	0.45	0.68	0.65	0.60	0.50	0.50	0.56
N. Toronto	0.70	0.73	0.63	0.75	0.85	0.63	0.71
Newmarket	0.58	0.54	0.58	0.53	0.58	0.55	0.56
Toronto Humber	0.70	0.73	0.68	0.83	0.78	0.63	0.73
Mean	0.62	0.65	0.64	0.66	0.64	0.59	0.63

* One application only.

[†] Values presented are averaged over nitrogen rates.

[§] Values presented are averaged over two soil pH values.

Significance of "F" test at 0.05 and 0.01 probability.

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.01
source x rate - 0.01
soil pH x rate - n.s.
soil pH x source - 0.01

TABLE 188. Potassium Concentration in Ryegrass at Two Soil pH Values. Third Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (Kg/ha)									
	pH 5.0					pH 7.0				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN
					% K					
None					4.79					4.25
Aurora	4.25	4.78	5.54	5.54	5.03	4.51	4.64	5.78	5.73	5.17
Midland	4.71	4.03	3.89	5.76	4.60	4.61	3.99	4.03	5.49	4.53
Point Edward	4.61	4.57	4.75	5.10	4.76	4.36	4.82	4.47	5.03	4.67
Sarnia	4.60	4.27	4.62	5.13	4.66	4.16	4.73	4.65	4.81	4.59
Guelph	4.50	3.77	4.53	5.80	4.65	4.15	4.60	5.39	5.18	4.83
Fergus	4.59	4.05	3.57	5.84	4.52	4.15	4.50	4.35	5.42	4.61
N. Toronto	4.47	3.85	3.88	5.81	4.50	4.33	3.79	4.16	5.49	4.45
Newmarket	3.78	4.06	4.53	5.40	4.45	4.61	4.09	4.52	5.70	4.73
Toronto Humber	4.17	4.31	4.98	5.68	4.78	4.59	4.58	4.56	4.96	4.67
Mean	4.41	4.19	4.48	5.56	4.66	4.39	4.42	4.66	5.31	4.69

*Sludge applied once only

Significance of "F" test at 0.05 and 0.01 probability

sludge source	.01	source x rate	.01
sludge rate	.01	source x soil pH	N.S.
soil pH	N.S.	soil pH x rate	N.S.
		source x rate x soil pH	.01

TABLE 189. Potassium Concentration in Ryegrass Averaged Over Two Soil pH Values. Third Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
			%-K		
None					4.52
Aurora	4.38	4.71	5.66	5.63	5.10
Midland	4.66	4.01	3.96	5.63	4.57
Point Edward	4.49	4.70	4.61	5.07	4.72
Sarnia	4.38	4.50	4.64	4.97	4.62
Guelph	4.33	4.19	4.96	5.49	4.74
Fergus	4.37	4.28	3.96	5.63	4.56
N. Toronto	4.40	3.82	4.02	5.65	4.47
Newmarket	4.20	4.08	4.52	5.55	4.59
Toronto Humber	4.38	4.45	4.77	5.32	4.73
Mean	4.40	4.30	4.57	5.44	4.68

* One sludge application only.

Significance of "F" test at 0.05 and 0.01 probability

sludge source - 0.01
sludge rate - 0.01
soil pH - N.S.

source x rate - 0.01
source x soil pH - N.S.
soil pH x rate - N.S.
source x rate x soil pH - 0.01

TABLE 190. Potassium Concentration in Ryegrass Averaged Over Two Soil pH Values. Fourth Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
			% K		
None					3.52
Aurora	3.10	4.45	4.66	3.89	4.03
Midland	3.75	3.18	3.55	3.28	3.44
Point Edward	3.32	2.66	3.36	3.27	3.15
Sarnia	3.92	3.20	3.83	3.35	3.58
Guelph	3.27	3.22	4.19	3.53	3.53
Fergus	3.30	3.30	3.60	3.49	3.42
N. Toronto	3.85	3.32	3.82	3.35	3.59
Newmarket	3.54	2.61	3.17	3.26	3.14
Toronto Humber	2.90	3.52	3.97	3.06	3.36
Mean	3.44	3.27	3.78	3.38	3.47

* One application of sludge only.

Significance of "F" test at 0.05 and 0.01 probability

sludge source	- 0.01	source x rate	- 0.01
sludge rate	- 0.01	source x soil pH	- N.S.
soil pH	- N.S.	soil pH x rate	- N.S.
		source x rate x soil pH	- N.S.

TABLE 191. Potassium Concentration in Ryegrass Averaged Over Two Soil pH Values. Fifth Crop, Greenhouse Experiment, 1975.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424 (1600)*	Mean
			% K		
None					4.05
Aurora	3.90	4.15	4.55	4.33	4.23
Midland	4.10	4.05	4.37	3.95	4.12
Point Edward	4.50	4.05	3.88	3.95	4.09
Sarnia	4.60	4.60	4.48	3.95	4.41
Guelph	4.40	4.98	4.88	4.68	4.73
Fergus	4.23	4.70	3.73	3.50	3.79
N. Toronto	4.08	3.48	3.68	4.35	3.89
Newmarket	3.98	3.38	4.03	4.25	3.91
Toronto Humber	4.10	4.13	4.85	4.00	4.27
Mean	4.21	4.06	4.27	4.11	4.16

* One application of sludge only.

Significance of "F" test at 0.05 and 0.01 probability.

sludge source - 0.01
sludge rate - n.s.
soil pH - n.s.
source x rate - 0.01
soil pH x rate - n.s.
soil pH x source - n.s.

TABLE 192. Calcium Concentration in Ryegrass at Two Soil pH Values. Third Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (Kg/ha)									
	pH 5.0					pH 7.0				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN
					% Ca					
None					0.38					0.75
Aurora	0.52	0.53	0.72	0.78	0.64	0.65	0.69	0.82	0.92	0.77
Midland	0.68	0.66	1.17	0.81	0.83	0.67	0.65	0.67	0.88	0.72
Point Edward	0.69	0.90	0.86	1.16	0.90	1.44	0.94	0.82	1.09	1.08
Sarnia	0.65	0.70	0.71	0.81	0.72	0.71	0.69	0.70	1.04	0.79
Guelph	0.69	0.83	0.60	0.82	0.74	0.65	0.81	0.63	1.02	0.78
Fergus	0.42	0.93	0.81	0.42	0.64	0.55	0.76	0.86	0.86	0.76
N. Toronto	0.49	0.95	0.60	0.59	0.66	0.65	0.95	0.88	1.06	0.89
Newmarket	0.87	0.79	0.70	1.09	0.87	0.84	0.95	0.59	1.04	0.86
Toronto Humber	0.61	0.79	0.70	0.64	0.69	0.75	0.81	0.84	1.05	0.86
Mean	0.63	0.79	0.77	0.79	0.74	0.77	0.81	0.76	1.00	0.83

*Sludge applied once only

Significance of "F" test at 0.05 and 0.01 probability

sludge source	.01	source x rate	.01
sludge rate	.01	source x soil pH	.05
soil pH	.01	soil pH x rate	.01
		source x rate x soil pH	.05

TABLE 193. Calcium Concentration in Ryegrass Averaged Over Two Soil pH Values. Third Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
			% Ca		
None					0.56
Aurora	0.56	0.61	0.77	0.85	0.71
Midland	0.68	0.65	0.92	0.85	0.78
Point Edward	1.07	0.92	0.84	1.13	0.99
Sarnia	0.68	0.70	0.71	0.93	0.75
Guelph	0.67	0.82	0.61	0.92	0.76
Fergus	0.48	0.84	0.84	0.64	0.70
N. Toronto	0.57	0.95	0.74	0.83	0.77
Newmarket	0.85	0.87	0.65	1.07	0.86
Toronto Humber	0.68	0.80	0.77	0.84	0.78
Mean	0.70	0.80	0.76	0.89	0.79

* Sludge applied only once.

Significance of "F" test at 0.05 and 0.01 probability

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.01

source x rate - 0.01
source x soil pH - 0.05
soil pH x rate - 0.01
source x rate x soil pH - 0.05

TABLE 194. Calcium Concentration in Ryegrass. Fourth Crop, Greenhouse Experiment.

Sludge	Original pH		Nitrogen Rate lb/ac (kg/ha)				
	5.0	7.0	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
					% Ca		
None	0.56	1.14					0.84
Aurora	0.89†	0.99	0.81§	1.12	0.96	0.87	0.94
Midland	0.90	0.89	0.90	0.96	0.93	0.80	0.90
Point Edward	1.11	1.18	0.89	1.31	1.30	1.08	1.14
Sarnia	1.03	0.98	0.83	1.15	1.20	0.85	1.01
Guelph	0.84	0.90	0.79	0.92	0.92	0.84	0.87
Fergus	0.78	0.90	0.61	1.00	1.14	0.61	0.84
N. Toronto	0.82	0.98	0.66	1.01	1.20	0.74	0.90
Newmarket	0.88	0.95	0.92	0.96	0.92	0.88	0.92
Toronto Humber	0.84	0.93	0.75	1.09	0.96	0.74	0.88
Mean	0.90	0.97	0.80	1.06	1.06	0.82	0.93

* One application of sludge only.
† Values presented are averaged over nitrogen rates.
§ Values presented are averaged over two soil pH values.

Significance of "F" test at 0.05 and 0.01 probability

sludge source	- 0.01	source x rate	- 0.01
sludge rate	- 0.01	source x soil pH	- N.S.
soil pH	- 0.01	soil pH x rate	- N.S.
		source x rate x soil pH	- N.S.

TABLE 195. Calcium Concentration in Ryegrass at Two Soil pH Values. Fifth Crop, Greenhouse Experiment, 1975.

Sludge	Original Soil pH									
	5.0					7.0				
	Nitrogen Rate (kg/ha)					Nitrogen Rate (kg/ha)				
	200	800	1600	1600*	Mean	200	800	1600	1600*	Mean
	% Ca									
None					0.85					1.55
Aurora	1.25	1.40	1.15	1.35	1.29	1.30	1.20	1.30	1.45	1.31
Midland	1.00	1.00	1.00	1.20	1.55	1.00	1.15	1.15	1.60	1.23
Point Edward	1.00	1.20	1.30	1.75	1.31	1.15	1.35	1.40	1.75	1.41
Sarnia	0.60	1.20	1.25	1.25	1.08	0.85	1.20	1.30	1.80	1.29
Guelph	1.00	1.05	1.15	1.25	1.11	1.20	0.90	1.10	1.75	1.24
Fergus	0.65	1.25	1.35	1.40	1.16	1.00	1.25	1.55	1.40	1.30
North Toronto	0.55	1.35	1.15	1.05	1.03	1.05	1.25	1.10	1.50	1.23
Newmarket	1.55	1.40	1.30	1.55	1.45	1.35	1.25	1.35	1.60	1.39
Toronto Humber	0.80	1.00	1.10	1.30	1.05	1.10	1.35	1.25	1.70	1.35

* One application only.

Source x rate x pH interaction is significant at 0.05 probability level by 'F' test.

TABLE 196. Calcium Concentration in Ryegrass Averaged Over Two Soil pH Values. Fifth Crop, Greenhouse Experiment, 1975.

Sludge	Nitrogen Rate lb/ac (kg/ha)				Mean
	178 (200)	712 (800)	1424 (1600)	1424 (1600) *	
			% Ca		
None					1.20
Aurora	1.28	1.30	1.23	1.40	1.30
Midland	1.00	1.08	1.18	1.58	1.21
Point Edward	1.08	1.28	1.35	1.75	1.36
Sarnia	0.73	1.20	1.28	1.53	1.18
Guelph	1.10	0.98	1.13	1.50	1.18
Fergus	0.83	1.25	1.45	1.40	1.23
N. Toronto	0.80	1.30	1.13	1.28	1.13
Newmarket	1.40	1.33	1.33	1.58	1.42
Toronto Humber	0.95	1.18	1.18	1.50	1.20
Mean	1.02	1.21	1.24	1.50	1.24

* One application only.

Significance of "F" test at 0.05 and 0.01 probability.

sludge soruce	- 0.01	source x rate	- 0.01
sludge rate	- 0.01	soil pH x rate	- 0.01
soil pH	- 0.01	soil pH x source	- 0.05

TABLE 197. Magnesium Concentration in Ryegrass at Two Soil pH Values. Third Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (Kg/ha)									
	pH 5.0					pH 7.0				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN
					% Mg					
None					0.19					0.21
Aurora	0.17	0.22	0.32	0.36	0.27	0.15	0.24	0.34	0.30	0.26
Midland	0.18	0.30	0.45	0.32	0.31	0.17	0.29	0.45	0.30	0.30
Point Edward	0.18	0.18	0.22	0.30	0.22	0.15	0.17	0.23	0.28	0.21
Sarnia	0.22	0.27	0.33	0.35	0.29	0.16	0.21	0.24	0.34	0.24
Guelph	0.21	0.33	0.23	0.33	0.28	0.13	0.25	0.23	0.32	0.24
Fergus	0.18	0.32	0.37	0.24	0.28	0.15	0.29	0.34	0.33	0.28
N. Toronto	0.17	0.31	0.29	0.33	0.28	0.14	0.24	0.26	0.32	0.24
Newmarket	0.12	0.20	0.22	0.21	0.19	0.10	0.20	0.19	0.16	0.17
Toronto Humber	0.18	0.28	0.28	0.29	0.26	0.15	0.21	0.27	0.31	0.24
Mean	0.18	0.27	0.30	0.30	0.26	0.15	0.24	0.29	0.30	0.24

*Sludge applied once only

Significance of "F" test at 0.05 and 0.01 probability

sludge source	.01	source x rate	.01
sludge rate	.01	source x soil pH	.01
soil pH	.01	soil pH x rate	.01
		source x rate x soil pH	.01

TABLE 198. Magnesium Concentration in Ryegrass Averaged Over Two Soil pH Values. Third Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
			% Mg		
None					0.20
Aurora	0.16	0.23	0.33	0.33	0.26
Midland	0.17	0.30	0.45	0.31	0.31
Point Edward	0.16	0.18	0.22	0.29	0.21
Sarnia	0.19	0.24	0.29	0.35	0.27
Guelph	0.17	0.29	0.23	0.32	0.25
Fergus	0.17	0.30	0.35	0.29	0.28
N. Toronto	0.16	0.28	0.27	0.33	0.26
Newmarket	0.11	0.20	0.21	0.19	0.18
Toronto Humber	0.17	0.25	0.28	0.30	0.25
Mean	0.16	0.25	0.29	0.30	0.25

* Sludge applied only once.

Significance of "F" test at 0.05 and 0.01 probability

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.01

source x rate - 0.01
source x soil pH - 0.01
soil pH x rate - 0.01
source x rate x soil pH - 0.01

TABLE 199. Magnesium Concentration in Ryegrass. Fourth Crop, Greenhouse Experiment.

Sludge	Original pH		Nitrogen Rate lb/ac (kg/ha)				
	5.0	7.0	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
					% Mg		
None	0.25	0.24					0.24
Aurora	0.36†	0.33	0.26§	0.42	0.43	0.27	0.34
Midland	0.39	0.37	0.27	0.44	0.59	0.24	0.38
Point Edward	0.29	0.25	0.22	0.31	0.34	0.21	0.30
Sarnia	0.42	0.38	0.26	0.47	0.56	0.32	0.40
Guelph	0.37	0.30	0.25	0.39	0.44	0.27	0.33
Fergus	0.32	0.29	0.25	0.38	0.36	0.24	0.30
N. Toronto	0.36	0.30	0.20	0.42	0.47	0.23	0.33
Newmarket	0.22	0.22	0.14	0.27	0.37	0.11	0.22
Toronto Humber	0.34	0.30	0.25	0.40	0.40	0.23	0.32
Mean	0.34	0.30	0.23	0.39	0.44	0.23	0.32

* One application of sludge only.
† Values presented are averaged over nitrogen rates.
§ Values presented are averaged over two soil pH values.

Significance of "F" test at 0.05 and 0.01 probability

sludge source	- 0.01	source x rate	- 0.01
sludge rate	- 0.01	source x soil pH	- 0.05
soil pH	- 0.01	soil pH x rate	- 0.01
		source x rate x soil pH	- N.S.

TABLE 200. Magnesium Concentration in Ryegrass Averaged Over Two Soil pH Values. Fifth Crop, Greenhouse Experiment, 1975.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424 (1600)*	Mean
			% Mg		
None					0.38
Aurora	0.45	0.43	0.43	0.48	0.44
Midland	0.30	0.45	0.63	0.53	0.48
Point Edward	0.28	0.33	0.45	0.43	0.37
Sarnia	0.28	0.45	0.53	0.58	0.46
Guelph	0.40	0.38	0.43	0.50	0.43
Fergus	0.28	0.40	0.38	0.45	0.38
N. Toronto	0.30	0.48	0.48	0.45	0.43
Newmarket	0.23	0.38	0.45	0.25	0.33
Toronto Humber	0.33	0.38	0.43	0.48	0.40
Mean	0.31	0.41	0.46	0.46	0.41

* One application only.

Significance of "F" test at 0.05 and 0.01 probability.

sludge source - 0.01
sludge rate - 0.01
soil pH - n.s.
source x rate - 0.01
soil pH x rate - n.s.
soil pH x source - n.s.

TABLE 201. Aluminum Concentration in Ryegrass Averaged Over Two Soil pH Values. Fourth Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
	Al Concentration - µg/g				
None					65
Aurora	31	29	28	46	33
Midland	39	24	15	63	35
Point Edward	80	60	28	57	56
Sarnia	43	39	27	42	37
Guelph	66	68	46	65	61
Fergus	76	44	121	76	79
N. Toronto	51	53	30	74	52
Newmarket	73	40	31	70	53
Toronto Humber	78	48	82	90	74
Mean	59	45	45	65	54

* One application only.

Significance of "F" test at 0.05 and 0.01 probability

sludge source - 0.01
sludge rate - 0.01
soil pH - N.S.

source x rate - 0.01
source x soil pH - N.S.
soil pH x rate - N.S.
source x rate x soil pH - N.S.

TABLE 202. Aluminum Concentration in Ryegrass. Fifth Crop, Greenhouse Experiment, 1975.

Sludge	Original soil pH		Nitrogen Rate lb/ac (kg/ha)				Mean
	5.0	7.0	178 (200)	712 (800)	1424 (1600)	1424 (1600)*	
				µg Al/g			
None	33[†]	36					34
Aurora	34	42	37[§]	50	23	42	38
Midland	42	26	40	27	23	46	34
Point Edward	51	44	42	54	62	33	47
Sarnia	43	38	36	57	28	41	40
Guelph	38	43	33	44	54	31	40
Fergus	57	60	53	42	99	40	59
N. Toronto	42	49	30	52	69	33	46
Newmarket	38	44	34	46	42	41	41
Toronto Humber	57	38	41	62	49	39	47
Mean	45	42	38	48	50	38	43
pH 5.0			38	57	43	41	45
7.0			39	39	56	35	42

* One application only.

[†] Values presented are averaged over nitrogen rates.

[§] Values presented are averaged over two soil pH values.

Significance of "F" test at 0.05 and 0.01 probability.

sludge source - 0.05
sludge rate - 0.05
soil pH - n.s.

source x rate - 0.01
soil pH x rate - 0.05
soil pH x source - n.s.

TABLE 203. Iron Concentration in Ryegrass Averaged Over Two Soil pH Values. Fourth Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
	Fe Concentration - µg/g				
None					163
Aurora	107	104	114	241	142
Midland	106	97	81	144	107
Point Edward	143	146	101	131	130
Sarnia	94	118	104	107	106
Guelph	118	163	121	135	134
Fergus	142	113	167	140	141
N. Toronto	104	144	107	152	127
Newmarket	136	114	105	126	120
Toronto Humber	147	128	175	158	152
Mean	122	125	119	148	129

* One application only.

Significance of "F" test at 0.05 and 0.01 probability

sludge source - 0.05
sludge rate - 0.05
soil pH - N.S.

source x rate - 0.05
source x soil pH - N.S.
soil pH x rate - N.S.
source x rate x soil pH - N.S.

TABLE 204. Manganese Concentration in Ryegrass at Two Soil pH Values. Third Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (Kg/ha)									
	pH 5.0					pH 7.0				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN
	Mn Concentration µg/g									
None					311					88
Aurora	284	42	197	113	159	45	47	310	33	109
Midland	180	119	95	49	111	149	109	64	91	103
Point Edward	59	52	95	140	86	61	51	90	160	90
Sarnia	482	135	263	255	284	43	182	164	158	137
Guelph	341	95	100	345	220	31	30	99	77	59
Fergus	339	361	1165	258	531	28	285	375	251	235
N. Toronto	448	312	225	364	337	46	88	117	78	82
Newmarket	72	117	42	154	96	34	77	75	112	74
Toronto Humber	339	288	270	260	289	43	27	158	41	67
Mean	283	169	272	215	235	53	99	161	111	106

*Sludge applied only once.

Significance of "F" test at 0.05 and 0.01 probability

sludge source	.01	source x rate	.01
sludge rate	.01	source x soil pH	.01
soil pH	.01	soil pH x rate	.01
		source x rate x soil pH	.01

TABLE 205. Manganese Concentration in Ryegrass Averaged Over Two Soil pH Values. Third Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
	Mn Concentration µg/g				
None					199
Aurora	164	44	254	73	134
Midland	165	114	80	70	107
Point Edward	60	52	92	150	88
Sarnia	263	159	214	206	210
Guelph	186	62	99	211	140
Fergus	184	323	770	254	383
N. Toronto	247	200	171	221	209
Newmarket	53	97	59	133	85
Toronto Humber	191	157	214	151	178
Mean	168	135	217	163	170

* Sludge applied only once.

Significance of "F" test at 0.05 and 0.01 probability

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.01

source x rate - 0.01
source x soil pH - 0.01
soil pH x rate - 0.01
source x rate x soil pH - 0.01

TABLE 206. Manganese Concentration in Ryegrass at Two Soil pH Values. Fourth Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (Kg/ha)									
	pH 5.0					pH 7.0				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN
	Mn Concentration - µg/g									
None					777					140
Aurora	422	69	62	71	156	65	46	153	75	85
Midland	120	101	98	62	95	102	102	54	96	89
Point Edward	96	45	72	38	63	56	38	80	41	53
Sarnia	323	89	197	72	170	45	83	144	33	76
Guelph	292	178	144	520	283	840	903	522	665	732
Fergus	840	903	523	666	732	47	379	670	197	323
N. Toronto	515	478	419	631	511	71	153	335	75	158
Newmarket	57	65	29	106	64	50	38	87	24	50
Toronto Humber	703	542	406	569	555	44	128	191	30	98
Mean	374	274	216	304	292	59	116	205	68	112

*One application of sludge only.

Significance of "F" test at 0.05 and 0.01 probability

sludge source	.01	source x rate	.01
sludge rate	N.S.	source x soil pH	.01
soil pH	.01	soil pH x rate	.01
		source x rate x soil pH	.01

TABLE 207. Manganese Concentration in Ryegrass Averaged Over Two Soil pH Values. Fourth Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
	Mn Concentration - µg/g				
None					458
Aurora	243	57	108	73	120
Midland	111	101	76	79	92
Point Edward	76	41	76	39	58
Sarnia	184	86	170	53	123
Guelph	174	128	138	280	180
Fergus	443	641	596	431	528
N. Toronto	293	316	377	353	335
Newmarket	53	51	58	65	57
Toronto Humber	373	335	298	299	326
Mean	217	195	211	186	202

* Sludge applied only once.

Significance of "F" test at 0.05 and 0.01 probability

sludge source	- 0.01	source x rate	- 0.01
sludge rate	- N.S.	source x soil pH	- 0.01
soil pH	- 0.01	soil pH x rate	- 0.01
		source x rate x soil pH	- 0.01

TABLE 208. Manganese Concentration in Ryegrass at Two Soil pH Values. Fifth Crop, Greenhouse Experiment.

Sludge	Original Soil pH									
	5.0					7.0				
	Nitrogen Rate (kg/ha)					Nitrogen Rate (kg/ha)				
	200	800	1600	1600*	Mean	200	800	1600	1600*	Mean
	µg/g									
None					1485					119
Aurora	73	42	68	53	59	33	42	141	59	69
Midland	69	84	41	54	62	62	117	48	92	80
Point Edward	29	17	41	38	31	29	35	18	45	32
Sarnia	372	17	29	36	113	26	33	48	28	34
Guelph	631	25	31	621	327	25	17	126	47	53
Fergus	765	540	297	563	541	63	83	318	101	141
North Toronto	684	114	189	954	485	28	54	131	59	68
Newmarket	35	48	26	62	42	22	37	81	26	41
Toronto Humber	293	243	308	315	290	38	22	164	41	66

* One application only.

Significance of 'F' test at 0.05 and 0.01 probability level.

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.01
source x rate - 0.01
soil pH x rate - 0.01
soil pH x source - 0.01

TABLE 209. Manganese Concentration in Ryegrass Averaged Over Two Soil pH Values. Fifth Crop, Greenhouse Experiment, 1975.

Sludge	Nitrogen Rate lb/ac (kg/ha)				Mean
	178 (200)	712 (800)	1424 (1600)	1424 (1600)*	
			µg Mn/g		
None					802
Aurora	53	42	104	56	64
Midland	65	101	44	73	71
Point Edward	29	26	29	41	31
Sarnia	199	25	38	32	73
Guelph	328	21	78	334	190
Fergus	414	311	308	332	341
N. Toronto	356	84	160	506	276
Newmarket	28	43	53	44	42
Toronto Humber	165	132	235	178	178
Mean	182	87	117	177	141

* One application only.

Significance of "F" test at 0.05 and 0.01 probability.

sludge source	- 0.01	source x rate	- 0.01
sludge rate	- 0.01	soil pH x rate	- 0.01
soil pH	- 0.01	soil pH x source	- 0.01

TABLE 210. Boron Concentration in Ryegrass. Fifth Crop, Greenhouse Experiment, 1975.

Sludge	Original soil pH		Nitrogen Rate lb/ac (kg/ha)				Mean
	5.0	7.0	178 (200)	712 (800)	1424 (1600)	1424 (1600)[*]	
				µg B/g			
None	13[†]	13					13
Aurora	13	16	12[§]	17	18	12	15
Midland	17	26	18	20	24	24	21
Point Edward	16	13	15	14	19	10	15
Sarnia	13	15	12	14	14	16	14
Guelph	16	15	11	16	19	14	15
Fergus	15	16	12	17	20	12	15
N. Toronto	15	14	17	13	16	12	14
Newmarket	15	14	12	14	17	15	14
Toronto Humber	18	17	11	20	26	13	17
Mean	15	16	13	16	19	14	16

[*] Sludge applied once only.

[†] Values presented are averaged over nitrogen rates.

[§] Values presented are averaged over two soil pH values.

Significance of "F" test at 0.05 and 0.01 probability.

sludge source	- 0.01	source x rate	- 0.05
sludge rate	- 0.01	soil pH x rate	- 0.01
soil pH	- n.s.	soil pH x source	- n.s.

TABLE 211. Cadmium Concentration in Ryegrass Averaged Over Two Soil pH Values. Third Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
	Cd Concentration - µg/g				
None					0.45
Aurora	0.37	0.47	0.67	0.40	0.48
Midland	0.27	0.27	0.35	0.38	0.32
Point Edward	0.30	0.20	0.35	0.45	0.32
Sarnia	0.62	0.90	0.85	0.92	0.82
Guelph	0.90	2.45	2.70	2.26	2.08
Fergus	0.42	0.96	1.26	0.95	0.90
N. Toronto	1.52	0.57	0.57	0.57	0.81
Newmarket	0.27	0.35	0.32	0.45	0.35
Toronto Humber	0.67	1.15	1.40	1.67	1.22
Mean	0.60	0.81	0.94	0.90	0.81

Significance of "F" Test at 0.05 and 0.01 Probability

sludge source - 0.01
sludge rate - 0.01
soil pH - n.s.

source x rate - 0.01
source x soil pH - n.s.
soil pH x rate - n.s.
source x rate x soil pH- n.s.

* One application of sludge only.

TABLE 212. Cadmium Concentration in Ryegrass at Two Soil pH Values. Fifth Crop, Greenhouse Experiment, 1975.

Sludge	Original Soil pH									
	5.0					7.0				
	Nitrogen Rate (kg/ha)					Nitrogen Rate (kg/ha)				
	200	800	1600	1600*	Mean	200	800	1600	1600*	Mean
					µg/g					
None					1.50					0.60
Aurora	0.60	0.60	0.40	0.90	0.63	0.50	0.50	0.55	0.60	0.54
Midland	0.35	0.35	0.40	0.50	0.40	0.20	0.50	0.60	0.65	0.49
Point Edward	0.60	0.45	0.50	0.45	0.50	0.40	0.40	0.70	0.35	0.46
Sarnia	0.70	1.05	0.90	0.95	0.90	0.50	1.10	1.50	1.15	1.06
Guelph	2.00	2.95	3.55	3.10	2.90	0.95	2.25	3.70	1.55	2.11
Fergus	0.95	0.75	0.65	1.40	0.94	0.40	0.60	0.95	1.15	0.78
North Toronto	0.60	0.60	0.70	0.95	0.71	0.50	0.60	0.65	0.65	0.60
Newmarket	0.45	0.45	0.40	0.55	0.46	0.40	0.30	0.55	0.50	0.44
Toronto Humber	0.90	1.40	1.30	2.50	1.53	0.85	1.35	1.05	1.75	1.25

* One application only.

TABLE 213. Cadmium Concentration in Ryegrass Averaged Over Two Soil pH Values. Fifth Crop, Greenhouse Experiment, 1975.

Sludge	Nitrogen Rate lb/ac (kg/ha)				Mean
	178 (200)	712 (800)	1424 (1600)	1424 (1600)*	
	µg Cd/g				
None					1.05
Aurora	0.55	0.55	0.48	0.75	0.58
Midland	0.28	0.43	0.50	0.58	0.44
Point Edward	0.50	0.43	0.60	0.40	0.48
Sarnia	0.60	1.08	1.20	1.05	0.98
Guelph	1.48	2.60	3.63	2.33	2.51
Fergus	0.68	0.68	0.80	1.28	0.86
N. Toronto	0.55	0.60	0.68	0.80	0.66
Newmarket	0.43	0.38	0.48	0.53	0.45
Toronto Humber	0.88	1.38	1.18	2.13	1.39
Mean	0.66	0.90	1.06	1.09	0.93

* One application only.

Significance of "F" test at 0.05 and 0.01 probability.

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.01
source x rate - 0.01
soil pH x rate - 0.01
soil pH x source - 0.01

TABLE 214. Cadmium Concentration in Five Crops of Ryegrass Receiving Ammonium Nitrate or Guelph Sewage Sludge.

Crop	Original Soil pH	Source and Rate of Nitrogen - lb/ac (kg/ha)				
		NH_4NO_3	Guelph Sludge			
		178 (200)	178 (200)	712 (800)	1424 (1600)	1424* (1600)
				µg Cd/g		
First	5.0	0.4	1.3	2.5	3.8	5.0
	7.0	0.5	1.0	2.1	2.6	2.0
Second	5.0	0.4	0.8	1.7	1.8	3.0
	7.0	0.4	1.0	2.6	5.5	1.8
Third	5.0	0.5	1.2	3.0	3.0	2.1
	7.0	0.4	0.6	1.9	2.5	2.4
Fourth	5.0	0.9	1.3	2.5	3.0	1.9
	7.0	0.3	0.8	2.3	3.0	1.8
Fifth	5.0	1.5	2.0	3.0	3.6	3.1
	7.0	0.6	0.9	2.3	3.7	1.6

* Applied once only.

TABLE 215. Copper Concentration in Ryegrass at Two Soil pH Values. Third Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (Kg/ha)									
	pH 5.0					pH 7.0				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN
	Cu Concentration - µg/g									
None					9					10
Aurora	7	11	12	18	12	11	12	13	7	10
Midland	9	13	16	13	13	12	13	14	13	13
Point Edward	15	13	11	11	12	13	14	13	19	14
Sarnia	10	11	13	12	12	11	10	11	12	11
Guelph	8	12	10	12	11	8	13	13	14	12
Fergus	8	16	41	16	20	9	16	15	15	13
N. Toronto	7	10	11	8	9	8	12	13	15	12
Newmarket	9	10	15	14	12	12	12	11	11	12
Toronto Humber	7	12	16	12	12	14	15	18	21	17
Mean	9	12	16	13	12	11	13	13	14	13

*Sludge applied only once.

Significance of "F" test at 0.05 and 0.01 probability.

sludge source	.01	source x rate	.01
sludge rate	.01	source x soil pH	.01
soil pH	n.s.	soil pH x rate	.01
		source x rate x soil pH	.01

TABLE 216. Copper Concentration in Ryegrass Averaged Over Two Soil pH Values. Third Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
	Cu Concentration µg/g				
None					10
Aurora	9	11	12	12	11
Midland	10	13	15	13	13
Point Edward	14	13	12	15	13
Sarnia	11	11	12	12	11
Guelph	8	12	11	13	11
Fergus	8	16	28	15	17
N. Toronto	7	11	12	12	10
Newmarket	10	11	13	13	12
Toronto Humber	10	13	17	17	14
Mean	10	12	14	13	12

* Sludge applied only once.

Significance of "F" test at 0.05 and 0.01 probability

sludge source - 0.01
sludge rate - 0.01
soil pH - n.s.

source x rate - 0.01
source x soil pH - 0.01
soil pH x rate - 0.01
source x rate x soil pH - 0.01

TABLE 217. Copper Concentration in Ryegrass at Two Soil pH Values. Fourth Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (Kg/ha)									
	pH 5.0					pH 7.0				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN
	Cu Concentration - µg/g									
None					14					14
Aurora	13	18	19	11	15	14	18	16	12	15
Midland	11	15	18	15	15	11	18	18	12	15
Point Edward	10	17	18	13	15	15	17	18	18	17
Sarnia	10	22	22	14	17	12	18	25	11	17
Guelph	12	25	20	13	17	13	20	24	18	19
Fergus	15	21	35	19	23	14	24	35	15	22
N. Toronto	11	18	18	13	15	11	17	19	15	15
Newmarket	15	17	24	10	16	9	14	18	9	13
Toronto Humber	16	16	18	14	16	12	19	16	13	15
Mean	13	19	21	14	17	12	18	21	14	16

*One application only.

Significance of "F" test at 0.05 and 0.01 probability			
sludge source	0.01	source x rate	0.01
sludge rate	0.01	source x soil pH	0.05
soil pH	n.s.	soil pH x rate	N.S.
		source x rate x soil pH	0.05

TABLE 218. Copper Concentration in Ryegrass Averaged Over Two Soil pH Values. Fourth Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
	Cu Concentration µg/g				
None					14
Aurora	14	18	17	11	15
Midland	11	17	18	13	15
Point Edward	13	17	18	16	16
Sarnia	11	20	24	13	17
Guelph	12	22	22	16	18
Fergus	14	23	35	17	22
N. Toronto	11	17	19	14	15
Newmarket	12	16	21	10	15
Toronto Humber	14	17	17	13	15
Mean	12	19	21	14	16

* One sludge application only.

Significance of "F" Test at 0.05 and 0.01 Probability

sludge source	- 0.01	source x rate	- 0.01
sludge rate	- 0.01	source x soil pH	- 0.05
soil pH	- n.s.	soil pH x rate	- N.S.
		source x rate x soil pH	- 0.05

TABLE 219. Copper Concentration in Ryegrass at Two Soil pH Values. Fifth Crop, Greenhouse Experiment, 1975.

Sludge	Original Soil pH									
	5.0					7.0				
	Nitrogen Rate (kg/ha)					Nitrogen Rate (kg/ha)				
	200	800	1600	1600*	Mean	200	800	1600	1600*	Mean
	µg Cu/g									
None					11					14
Aurora	13	15	17	13	14	13	15	18	12	14
Midland	13	18	18	16	16	10	17	21	21	17
Point Edward	15	15	23	15	17	16	14	19	20	17
Sarnia	15	23	23	23	21	14	17	20	18	17
Guelph	13	17	21	27	19	13	17	22	16	17
Fergus	19	25	21	22	21	15	19	26	22	20
North Toronto	13	20	21	21	17	10	16	18	14	14
Newmarket	14	15	16	15	15	14	17	18	19	17
Toronto Humber	14	20	22	16	18	14	20	21	15	17
Mean	14	19	20	17	17	13	17	20	17	17

* One application only

TABLE 220. Copper Concentration of Ryegrass Averaged Over Two Soil pH Values. Fifth Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)				Mean
	178 (200)	712 (800)	1424 (1600)	1424 (1600)*	
			µg Cu/g		
None					12
Aurora	13	15	17	12	14
Midland	12	18	19	18	17
Point Edward	15	15	21	17	17
Sarnia	14	20	21	20	19
Guelph	13	17	21	21	18
Fergus	17	22	24	22	21
N. Toronto	11	18	20	13	15
Newmarket	14	16	17	17	16
Toronto Humber	14	20	21	15	17
Mean	13	18	20	17	17

* One application only

Significance of "F" test at 0.05 and 0.01 probability.

sludge source	- 0.01	source x rate	- 0.05
sludge rate	- 0.01	soil pH x rate	- N.S.
soil pH	- N.S.	soil pH x source	- 0.05

TABLE 221. Copper Concentration in Five Crops of Ryegrass Receiving Ammonium Nitrate and Fergus Sewage Sludge.

		Source and Rate of Nitrogen - lb/ac (kg/ha)				
			Fergus Sludge			
Crop	Original Soil pH	NH_4NO_3- 178 (200)	178 (200)	712 (800)	1424 (1600)	1424* (1600)
			µg Cu/g			
1st	5.0	10	52	43	56	31
	7.0	10	35	46	21	21
2nd	5.0	20	25	43	37	-
	7.0	17	23	35	-	40
3rd	5.0	9	8	16	40	16
	7.0	10	9	16	15	15
4th	5.0	14	14	21	35	18
	7.0	14	14	24	35	15
5th	5.0	11	19	25	21	22
	7.0	14	15	19	26	22

* Applied once only

TABLE 222. Dry Matter Yield of Five Crops of Ryegrass Receiving Ammonium Nitrate and Fergus Sewage Sludge.

Crop	Source and Rate of Nitrogen - lb/ac (kg/ha)				
	NH_4NO_3	Fergus Sludge			
	178 (200)	178 (200)	712 (200)	1424 (1600)	1424* (1600)
	dry matter - g/pot				
1st	7.8	9.2	4.7	4.8	4.0
2nd	7.4	7.5	4.0	2.6	2.9
3rd	8.0	5.2	4.5	2.3	5.4
4th	9.7	6.8	6.0	1.5	7.2
5th	5.1	4.3	3.4	2.1	4.5

* Sludge applied once only.

TABLE 223. Effect of Rate of Application of Sludge on Chromium Concentration in Ryegrass. Fifth Crop, Greenhouse Experiment, 1975.

	Rate of Sludge Application lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424 (1600)*	Mean
Cr concentration in ryegrass µg/g	0.8	0.9	1.1	0.9	0.9

* One application only

TABLE 224. Nickel Concentration in Ryegrass at Two Soil pH Values. Third Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)									
	Original soil pH - 5.0					Original soil pH - 7.0				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN
	Ni Concentration - µg/g									
None					5.0					0.5
Aurora	1.5	0.5	1.0	1.5	1.1	1.0	0.5	1.5	1.5	1.1
Midland	17.0	22.5	35.0	36.6	27.8	14.5	22.5	34.5	37.0	27.1
Point Edward	1.5	0.6	0.5	1.0	0.9	1.0	0.4	0.5	0.5	0.6
Sarnia	2.0	1.0	1.5	2.5	1.8	0.5	0.5	1.5	1.5	1.0
Guelph	3.5	4.5	3.0	8.5	4.9	0.5	1.5	2.0	1.4	1.4
Fergus	7.0	16.4	22.4	7.0	13.2	1.0	9.0	12.5	4.0	6.6
N. Toronto	3.5	5.5	4.0	6.0	4.8	1.0	0.5	2.0	1.5	1.3
Newmarket	1.0	1.0	0.5	2.0	1.1	1.5	0.5	0.5	0.5	0.8
Toronto Humber	11.5	24.0	26.5	24.5	21.6	0.5	5.0	15.0	5.0	6.4
Mean	5.4	8.4	10.5	10.0	8.6	2.4	4.5	7.8	5.9	5.1

*One application only.

Significance of "F" test at 0.05 and 0.01 probability

sludge source	.01	source x rate	.01
sludge rate	.01	source x soil pH	.01
soil pH	.01	soil pH x rate	.01
		source x rate x soil pH	.01

TABLE 225. Nickel Concentration in Ryegrass Averaged Over Two Soil pH Values. Third Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
	Ni Concentration - μg/g				
None					2.8
Aurora	1.3	0.5	1.3	1.5	1.1
Midland	15.8	22.5	34.8	36.8	27.4
Point Edward	1.3	0.5	0.5	0.8	0.8
Sarnia	1.3	0.8	1.5	2.0	1.4
Guelph	2.0	3.0	2.5	4.9	3.1
Fergus	4.0	12.7	17.5	5.5	9.9
N. Toronto	2.3	3.0	3.0	3.8	3.0
Newmarket	1.3	0.8	0.5	1.3	0.9
Toronto Humber	6.0	14.5	20.8	14.8	14.0
Mean	3.9	6.5	9.1	7.9	6.9

* Sludge applied once only.

Significance of "F" test at 0.05 and 0.01 probability

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.01

source x rate - 0.01
source x soil pH - 0.01
soil pH x rate - 0.01
source x rate x soil pH - 0.01

TABLE 226. Nickel Concentration in Ryegrass Averaged Over Two Soil pH Values. Fourth Crop, Greenhouse Experiment, 1975.

Sludge	Nitrogen Rate lb/ac (kg/ha)				Mean
	178 (200)	712 (800)	1424 (1600)	1424 (1600)*	
	µg Ni/g				
None					2.5
Aurora	12.0	12.1	5.6	5.1	8.7
Midland	18.9	30.3	46.0	40.5	33.9
Point Edward	12.6	11.8	10.7	7.0	10.5
Sarnia	5.2	3.6	3.9	4.8	4.4
Guelph	8.1	16.1	6.1	5.8	9.0
Fergus	6.4	17.4	23.2	5.1	13.0
N. Toronto	6.8	4.9	6.2	7.0	6.2
Newmarket	3.7	3.9	2.5	3.2	3.3
Toronto Humber	9.2	22.6	20.8	13.6	16.5
Mean	9.2	13.6	13.9	10.2	11.7
pH 5.0	10.2	13.6	14.7	11.8	12.6
7.0	8.3	13.6	13.1	8.6	10.9

* One application only
Significance of "F" test at 0.05 and 0.01 probability

sludge source - 0.01
sludge rate - 0.01
soil pH - n.s.
source x rate - 0.01
soil pH x rate - n.s.
soil pH x source - 0.05

TABLE 227. Nickel Concentration in Ryegrass at Two Soil pH Values. Fifth Crop, Greenhouse Experiment, 1975.

Sludge	Original Soil pH									
	5.0					7.0				
	Nitrogen Rate (kg/ha)					Nitrogen Rate (kg/ha)				
	200	800	1600	1600*	Mean	200	800	1600	1600*	Mean
	µg Ni/g									
None					4.5					3.0
Aurora	3.0	2.5	3.0	2.5	2.8	1.5	2.5	2.0	2.0	2.0
Midland	9.5	19.5	25.5	27.5	20.5	8.0	23.0	29.0	20.0	20.0
Point Edward	2.5	1.0	2.0	1.5	1.8	3.0	2.5	2.5	3.0	2.8
Sarnia	3.0	1.5	2.0	1.5	2.0	2.5	1.0	1.0	3.0	1.9
Guelph	3.0	1.5	2.5	8.5	3.9	2.0	2.0	3.0	2.5	2.4
Fergus	7.0	12.0	12.0	6.0	9.3	1.5	6.5	16.0	2.0	6.5
North Toronto	3.0	4.0	5.5	5.0	4.4	1.0	1.5	3.5	2.0	2.0
Newmarket	2.0	2.0	1.0	1.0	1.5	2.0	2.5	2.0	2.0	2.1
Toronto Humber	7.5	19.0	16.0	22.0	16.1	2.5	5.5	10.5	3.5	5.5

* One application only

TABLE 228. Nickel Concentration in Ryegrass Averaged Over Two Soil pH Values. Fifth Crop, Greenhouse Experiment, 1975.

	Nitrogen Rate lb/ac (kg/ha)				
Sludge	178 (200)	712 (800)	1424 (1600)	1424 (1600)*	Mean
			µg Ni/g		
None					3.0
Aurora	2.3	2.5	2.5	2.3	2.4
Midland	8.8	21.3	27.3	23.4	20.3
Point Edward	2.8	1.8	2.3	2.3	2.3
Sarnia	2.8	1.3	1.5	2.3	1.9
Guelph	2.5	1.8	2.8	5.5	3.1
Fergus	4.3	9.3	14.0	4.0	7.9
N. Toronto	2.0	2.7	4.5	3.5	3.2
Newmarket	2.0	2.3	1.5	1.5	1.8
Toronto Humber	5.0	12.3	13.3	12.8	10.9
Mean	3.6	6.1	7.7	6.4	6.0

* One application only

Significance of "F" test at 0.05 and 0.01 probability.

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.01
source x rate - 0.01
soil pH x rate - 0.01
soil pH x source - 0.01

TABLE 229. Nickel Concentration in Five Crops of Ryegrass Resulting from Application of Ammonium Nitrate and Nine Sewage Sludges.

		Source and Rate of Nitrogen - lb/ac (kg/ha)				
	Original	NH_4NO_3	Sewage Sludge			
	Soil	178	178	712	1424	1424*
Crop	pH	(200)	(200)	(800)	(1600)	(1600)
			µg Ni/g			
1st	5.0	4.3	7.9	10.7	14.0	13.6
	7.0	2.0	3.5	6.8	7.6	7.8
2nd	5.0	3.6	8.4	8.3	9.8	12.9
	7.0	1.8	3.0	6.7	7.4	6.7
3rd	5.0	5.0	5.4	8.4	10.4	9.9
	7.0	0.5	2.4	4.5	7.7	5.9
4th	5.0	7.7	10.2	13.6	14.7	11.8
	7.0	10.5	8.3	13.6	13.1	8.6
5th	5.0	4.5	4.5	7.0	7.7	8.4
	7.0	3.0	2.7	5.2	7.7	4.4

* Applied once only.

TABLE 230. Nickel Concentration in Five Crops of Ryegrass Resulting from Application of Ammonium Nitrate and Midland Sewage Sludge.

	Source and Rate of Nitrogen - lb/ac (kg/ha)				
	NH_4HO_3	Midland Sewage Sludge			
Crop	178 (200)	178 (200)	712 (800)	1424 (1600)	1424* (1600)
			Ni µg/g		
Ist	3	16	39	47	47
2nd	3	30	35	45	48
3rd	3	16	22	35	37
4th	-	19	30	46	41
5th	4	9	21	27	24
			Total Ni Added kg/ha		
5th		210	840	1680	473

* Sludge applied once only

TABLE 231. Effect of Different Sources of Sludge on Lead Concentration* in Ryegrass. Third and Fifth Crops, Greenhouse Experiment, 1975.

Sludge Source	3rd Crop	5th Crop
	Pb μg/g	
None	5.0	2.0
Aurora	5.4	2.0
Midland	5.1	1.8
Point Edward	5.3	2.2
Sarnia	6.0	2.6
Guelph	5.5	2.1
Fergus	5.6	2.4
N. Toronto	6.1	1.8
Newmarket	4.5	1.8
Toronto Humber	4.5	1.6
Mean	5.3	2.0

* Averaged over rate and soil pH. Effect of sources of sludge is significant at 0.05 probability level by "F" test in both crops.

TABLE 232. Zinc Concentration in Ryegrass at Two Soil pH Values. Third Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (Kg/ha)									
	pH 5.0					pH 7.0				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN	178 (200)	712 (800)	1424 (1600)	1424* (1600)	MEAN
	Zn Concentration - µg/g									
None					64					31
Aurora	36	28	32	65	40	25	18	36	20	25
Midland	35	36	44	48	41	32	35	44	45	39
Point Edward	50	44	48	45	47	41	38	48	53	45
Sarnia	136	174	239	234	196	92	146	245	200	171
Guelph	94	132	116	268	152	43	97	126	160	106
Fergus	188	482	376	436	370	72	299	338	222	233
N. Toronto	70	148	153	145	129	41	70	102	81	73
Newmarket	25	34	56	47	40	21	36	57	44	39
Toronto Humber	83	143	187	201	153	60	89	160	116	106
Mean	79	136	139	165	130	47	92	128	104	93

*Sludge applied only once.

Significance of "F" test at 0.05 and 0.01 probability			
sludge source	.01	source x rate	.01
sludge rate	.01	source x soil pH	.01
soil pH	.01	soil pH x rate	.01
		source x rate x soil pH	.01

TABLE 233. Zinc Concentration in Ryegrass Averaged Over Two Soil pH Values. Third Crop, Greenhouse Experiment.

Sludge	Nitrogen Rate lb/ac (kg/ha)				
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
	Zn Concentration µg/g				
None					48
Aurora	29	23	34	42	32
Midland	34	35	44	46	40
Point Edward	46	41	48	49	46
Sarnia	114	160	242	217	183
Guelph	68	114	121	214	129
Fergus	130	391	357	329	302
N. Toronto	56	109	127	113	101
Newmarket	23	35	56	45	40
Toronto Humber	71	116	174	159	130
Mean	63	114	134	135	111

* Sludge applied only once.

Significance of "F" test at 0.05 and 0.01 probability

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.01

source x rate - 0.01
source x soil pH - 0.01
soil pH x rate - 0.01
source x rate x soil pH - 0.01

TABLE 234. Zinc Concentration in Ryegrass. Fourth Crop, Greenhouse Experiment.

Sludge	Original pH		Nitrogen Rate lb/ac (kg/ha)				
	5.0	7.0	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean
			Zn Concentration - µg/g				
None	54	32					43
Aurora	33†	27	26§	38	33	23	30
Midland	39	40	26	43	56	32	39
Point Edward	38	35	31	41	46	29	37
Sarnia	158	104	77	166	159	121	131
Guelph	118	86	60	112	131	105	102
Fergus	318	214	112	295	496	161	266
N. Toronto	112	62	46	110	132	61	87
Newmarket	39	33	18	33	59	34	36
Toronto Humber	107	74	66	99	117	80	91
Mean	107	75	51	104	137	72	91

* One application only.
† Values presented are averaged over nitrogen rates.
§ Values presented are averaged over two soil pH values.

Significance of "F" test at 0.05 and 0.01 probability

sludge source	- 0.01	source x rate	- 0.01
sludge rate	- 0.01	source x soil pH	- 0.01
soil pH	- 0.01	soil pH x rate	- N.S.
		source x rate x soil pH	- N.S.

TABLE 235. Zinc Concentration in Ryegrass. Fifth Crop, Greenhouse Experiment 1, 1975.

Sludge	pH		Nitrogen Rate lb/ac (kg/ha)				Mean
	5.0	7.0	178 (200)	712 (800)	1424 (1600)	1424 (1600)*	
			µg Zn/g				
None	51^+	33					42
Aurora	31	25	$22^{\S}$	31	35	25	28
Midland	29	34	20	36	41	30	32
Point Edward	26	24	19	26	31	23	25
Sarnia	122	110	51	136	161	116	116
Guelph	88	65	46	77	84	98	76
Fergus	188	122	77	214	135	195	155
N. Toronto	81	58	38	83	80	77	70
Newmarket	32	31	17	33	52	24	31
Toronto Humber	90	70	50	75	116	80	80
Mean	76	60	38	79	82	74	68

* Sludge applied only once
+ Values presented are averaged over nitrogen rates
§ Values presented are averaged over two soil pH values

Significance of "F" test at 0.05 and 0.01 probability.

sludge source - 0.01
sludge rate - 0.01
soil pH - 0.01

source x rate - 0.01
soil pH x rate - n.s.
soil pH x source - 0.05

TABLE 236. Zinc Concentration in Five Crops of Ryegrass Resulting from Application of Ammonium Nitrate and Nine Sewage Sludges.

		Source and Rate of Nitrogen - lb/ac (kg/ha)				
	Original	NH_4NO_3	Sewage Sludge			
	Soil	178	178	712	1424	1424*
Crop	pH	(200)	(200)	(800)	(1600)	(1600)
		µg Zn/g				
1st	5.0	61	81	128	171	181
	7.0	43	44	63	79	82
2nd	5.0	86	102	113	112	129
	7.0	38	48	98	91	100
3rd	5.0	64	79	135	108	166
	7.0	31	47	92	128	105
4th	5.0	54	61	123	155	89
	7.0	32	42	86	118	55
5th	5.0	51	45	85	83	92
	7.0	33	30	73	80	56

* Applied once only.

TABLE 237. Molybdenum Concentration in Ryegrass. Third, Fourth, and Fifth Crops, Greenhouse Experiment, 1975.

Treatments	Original Soil pH					
	pH 5			pH 7		
	3rd	4th	5th	3rd	4th	5th
			μg/g			
Control- NH_4NO_3, 200 kg N/ha	0.25	0.25	0.15	0.25	0.26	0.27
Midland sludge, 800 kg N/ha	0.72	0.40	0.45	0.72	0.37	0.50
Midland sludge, 1600 kg N/ha	0.71	0.41	0.43	0.68	0.29	0.50
Guelph sludge, 800 kg N/ha	0.86	0.35	0.61	0.79	0.51	0.40
Guelph sludge, 1600 kg N/ha	1.10	0.52	0.61	1.32	0.86	0.48
Toronto Humber sludge, 800 kg N/ha	1.33	0.49	0.41	1.10	0.31	0.66
Toronto Humber sludge, 1600 kg N/ha	1.85	1.05	0.68	1.17	0.67	0.55

TABLE 238. Mercury Concentration in Ryegrass. Third, Fourth, and Fifth Crops, Greenhouse Experiment, 1975.

Treatments	Original soil pH					
	pH 5			pH 7		
	3rd	4th	5th	3rd	4th	5th
			µg/g			
Control - NH_4NO_3, 200 kg N/ha	0.37	0.15	-	0.28	0.31	-
Midland sludge 800 kg N/ha	0.37	0.16	0.27	0.28	0.18	-
" " 1600 kg N/ha	0.29	0.14	0.26	0.34	0.16	0.19
Sarnia sludge, 800 kg N/ha	0.24	0.15	0.26	0.37	0.16	0.23
" " 1600 kg N/ha	0.37	0.14	0.25	0.33	0.14	0.22
N. Toronto sludge, 800 kg N/ha	0.22	0.17	0.24	0.18	0.16	0.24
" " 1600 kg N/ha	0.22	0.15	0.27	0.19	0.15	0.25

TABLE 239. Selenium Concentration in Ryegrass. Third, Fourth, and Fifth Crops, Greenhouse Experiment, 1975.

Treatments	pH - 5.0			pH - 7.0		
	3rd	4th	5th	3rd	4th	5th
	µg Se/g					
Control- NH_4NO_3, 200 kg N/ha	.020	.060	.120	-	-	.045
Aurora sludge, 800 kg N/ha	.033	.065	.120	.028	.255	.040
Aurora sludge, 1600 kg N/ha	.030	.060	.040	.030	.085	.055
Guelph sludge, 800 kg N/ha	.025	.130	.030	.063	.001	.065
Guelph sludge, 1600 kg N/ha	.043	.105	.140	.060	.075	.080
Toronto Humber sludge, 800 kg N/ha	.035	.125	.050	.038	.045	.045
Toronto Humber sludge, 1600 kg N/ha	.040	.180	.080	.035	.001	.080

TABLE 240. Characteristics of Soil Used in Greenhouse Experiment II.

	pH	O.M. %	Clay %	CEC meq/100 g
Minimum	5.2	1.4	2.7	5.4
Maximum	7.9	17.0	54.0	67.4
Mean	7.0	4.8	19.0	29.3

TABLE 241. Metals Extracted from Soils Used in Experiment II by Aqua Regia.

	Cd	Cu	Ni	Pb	Zn
		µ g/g			
Minimum	0.50	10	3	15	20
Maximum	9.25	325	525	1250	745
Mean	1.76	66	59	118	206
Mean (Ont.)*	0.7	25	16	14	54

*R.A. Frank et al, Ontario Ministry of Agriculture and Food, Pesticide Laboratory, Guelph Ont. Personal communication.

TABLE 242. Metal Concentrations in Swiss Chard Leaves.

	Cd	Cu	Ni	Pb	Zn
		µ g/g			
Minimum	0.01	7.0	0.0	2.5	29
Maximum	8.45	41.0	48.2	11.0	1550
Mean	1.55	18.7	4.6	4.7	220

TABLE 243. Equations Using Stepwise Regression for the Prediction of Cadmium Concentration in Swiss Chard Using Extractable Metals and Other Soil Characteristics as Independent Variables.

Regression Step	R^2	Variable added	Final Equation coefficient	Final Equation F ratio
		Extractant - H_2O		
1	0.72	Cd x CEC	9.25	99.7**
2	0.76	Cu^2	15.7	6.9*
		Constant	0.755	
		Extractant - DTPA		
1	0.35	Cd	0.981	13.1**
2	0.62	pH	-11.9	11.3**
3	0.72	pH^2	0.811	9.6**
4	0.77	Cd x OM	-0.0193	13.8**
5	0.80	Cd x pH	-0.106	7.8**
		Constant	43.8	
		Extractant - EDTA		
1	0.34	Cd	12.2	17.8**
2	0.61	pH	-9.60	7.76**
3	0.71	pH^2	0.656	6.78*
4	0.76	Cd x OM	---	---
5	0.80	Cd x pH	-1.35	12.4**
6	0.82	Cd^2	-0.364	18.8**
7	0.83	CEC x OM	-0.00197	10.7**
8	0.83	Cd x OM deleted		
		Constant	35.2	
		Extractant - NTA		
1	0.69	Cd^2	0.517	29.2**
2	0.81	Cd x OM	-0.396	51.0**
3	0.88	pH	-1.70	29.0**
4	0.90	Cd	1.87	7.0*
		Constant	13.1	

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* Significant at 0.05 probability level.

** Significant at 0.01 probability level.

TABLE 243. (Continued)

Regression Step	R^2	Variable added	Final Equation coefficient	Final Equation F ratio
		Extractant - CH_3COONH_4		
1	0.34	pH	-15.0	20.6**
2	0.57	Cd	0.335	13.5**
3	0.65	pH^2	1.01	17.0**
4	0.70	Zn^2	0.00798	34.0**
5	0.77	Zn x OM	-0.0724	25.5**
6	0.80	Cu x CEC	0.0146	10.1**
7	0.83	pH x OM	0.0210	6.3*
		Constant	55.5	
		Extractant - CH_3COOH		
1	0.34	pH	-11.2	10.4**
2	0.64	Cd	0.756	25.5**
3	0.73	Cd^2	-0.00335	11.5**
4	0.78	Cd x pH	-0.0713	12.6**
5	0.81	pH^2	0.738	8.1**
		Constant	42.0	
		Extractant - $HCl + AlCl_3$		
1	0.42	Cd	16.3	173.0**
2	0.70	Cd x clay	-0.95	57.7**
3	0.87	Cd x pH	-1.79	98.4**
4	0.91	Cd x OM	-0.167	14.5**
5	0.93	clay	0.053	8.5**
		Constant	-0.278	

TABLE 244. Equations Developed Using Stepwise Regression for the Prediction of Copper Concentration in Swiss Chard Using Extractable Metals and Other Soil Characteristics as Independent Variables.

Regression Step	R^2	Variable added	Final Equation coefficient	Final Equation F Ratio
		Extractant - H_2O		
1	0.41	Zn x OM	17.3	44.3**
2	0.57	Zn x CEC	-1.27	37.2**
3	0.63	Cu	36.7	16.2**
4	0.70	Cd x OM	-248.0	11.4**
5	0.72	pH^2	-0.190	5.7*
6	0.76	Clay x CEC	-0.00277	5.5*
		Constant	25.4	
		Extractant - DTPA		
1	0.50	Zn	0.324	9.1**
2	0.60	Zn x pH	-0.0392	5.8*
3	0.66	pH x CEC	-0.0878	13.3**
4	0.69	OM x CEC	0.0786	6.5*
5	0.72	OM^2	-0.202	5.1*
		Constant	26.8	
		Extractant - EDTA		
1	0.53	Zn	0.0464	54.7**
2	0.62	Zn x pH	---	---
3	0.68	CEC x pH	-0.191	42.5**
4	0.71	CEC x OM	0.204	28.9**
5	0.74	OM^2	-0.475	24.5**
6	0.76	CEC^2	-0.0226	20.7**
7	0.82	CEC	1.31	24.5**
8	0.82	Zn x pH deleted		
		Constant	20.5	

TABLE 244. (Continued)

Regression Step	R^2	Variable added	Final Equation coefficient	F Ratio
		Extractant - NTA		
1	0.34	Cu	1.579	23.6**
2	0.49	Cu x pH	-0.190	17.5**
3	0.56	Cu x OM	-0.0201	6.4*
		Constant	15.1714	
		Extractant - CH_3COONH_4		
1	0.61	Zn	0.635	59.8**
2	0.64	pH^2	-0.160	4.4*
		Constant	22.7	
		Extractant - CH_3-COOH		
1	0.52	Zn	0.0444	58.1**
2	0.58	pH	-4.38	20.9**
3	0.65	pH x CEC	---	---
4	0.70	OM	1.04	9.9**
5	0.72	Pb^2	0.000361	4.9*
6	0.74	CEC^2	-0.00522	15.5**
7	0.74	pH x CEC deleted		
		Constant	46.45	
		Extractant - HCl + $AlCl_3$		
1	0.33	Cu	1.541	35.8**
2	0.46	Cu x pH	-0.1869	27.6**
3	0.57	Cu^2	-0.00094	16.9**
4	0.66	CEC	-0.1723	11.1**
		Constant	18.541	

*Significant at 0.05 probability level.

**Significant at 0.01 probability level.

TABLE 245. Equations Using Stepwise Regression for the Prediction of Nickel Concentration in Swiss Chard Using Extractable Metals and Other Soil Characteristics as Independent Variables.

Regression Step	R^2	Variable added	Final equation coefficient	Final equation F ratio
		Extractant - H_2O		
1	0.44	Ni^2	-422	20.4**
2	0.49	pH^2	---	---
3	0.55	Cd x OM	-81.3	11.9**
4	0.57	Ni x pH	-62.3	62.6**
5	0.73	Ni	757	113.9**
6	0.80	Ni x CEC	-1.99	35.3**
7	0.84	Cu^2	-88.3	16.6**
8	0.84	pH^2 deleted		
9	0.88	Ni x clay	-2.23	11.1**
		Constant	1.09	
		Extractant - DTPA		
1	0.18	Ni	3.76	82.6**
2	0.48	Ni x OM	0.0725	87.5**
3	0.81	Ni x pH	-0.411	39.6**
4	0.87	Ni x clay	-0.00903	17.9**
5	0.91	Ni^2	0.00337	16.2**
		Constant	1.74	
		Extractant - EDTA		
1	0.17	Ni	10.5	96.5**
2	0.46	Ni x pH	-1.18	49.4**
3	0.85	Ni x CEC	-0.0252	135.4**
4	0.90	Ni x clay	-0.0234	15.9**
		Constant	1.50	

TABLE 245. (Continued)

Regression Step	R^2	Variable added	Final equation coefficient	F ratio
		Extractant - NTA		
1	0.82	Ni^2	-0.00183	14.7**
2	0.86	Ni x OM	-0.03155	76.4**
3	0.90	Ni	1.1294	69.6**
4	0.95	Ni x clay	-0.01497	38.5**
		Constant	1.0143	
		Extractant - CH_3COOH		
1	0.43	Ni	56.6	132.4**
2	0.82	Ni x pH	-7.09	100.7**
3	0.86	Ni x OM	-0.252	10.6**
4	0.88	Cd x clay	-0.00449	8.1**
		Constant	2.37	
		Extractant - $HCl + AlCl_3$		
1	0.73	Ni^2	0.00295	768.1**
2	0.87	Ni x OM	-0.1197	141.2**
3	0.95	Ni x CEC	0.02368	107.7**
4	0.97	Ni x clay	-0.00277	14.7**
		Constant	2.1427	

*Significant at 0.05 probability level.

**Significant at 0.01 probability level.

TABLE 246. Equations Using Stepwise Regression for the Prediction of Lead Concentration in Swiss Chard Using Extractable Metals and Other Soil Characteristics as Independent Variables.

Regression Step	R^2	Variable added	Final Equation	
			Coefficient	F ratio
		Extractant - H_2O		
1	0.10	CEC x clay	-0.00115	5.08*
		Constant	5.44	
		Extractant - EDTA		
1	0.36	Pb x pH	0.006757	38.3**
2	0.52	Pb x clay	-0.00155	9.1**
3	0.57	Cd x pH	-0.0444	5.2*
		Constant	4.351	
		Extractant - DTPA		
1	0.33	Pb x pH	-0.0146	10.1**
2	0.50	Pb x clay	-0.00281	25.9**
3	0.56	Cd x pH	0.0241	4.9*
4	0.58	CEC x pH	-0.00593	7.2*
5	0.60	Pb	0.179	20.2**
6	0.60	Pb x pH deleted	-0.0146	10.1**
7	0.63	Pb^2	-0.000108	13.5**
8	0.65	Pb x pH re-added	-	
9	0.68	Zn	-0.0593	16.2**
10	0.70	Zn x CEC	0.00191	14.2**
11	0.74	Cd x CEC	0. 00653	8.2*
12	0.78	$Clay^2$	0.000654	5.3*
		Constant	4.97	

TABLE 246. (Continued)

Regression Step	R^2	Variable added	Final Equation	
			Coefficient	F ratio
		Extractant - NTA		
1	0.39	Pb x pH		
2	0.53	Pb x clay	-0.00153	5.15*
3	0.57	Pb	0.0575	16.8**
4		Pb x pH deleted		
5	0.57	$clay^2$	0.00277	4.7*
6	0.60	clay	-0.1389	3.7*
7	0.62	Pb^2	-0.000085	1.7
		Constant	5.084	
		Extractant - Aqua regia		
1	0.11	Cd x Clay	-0.0217	17.1**
2	0.30	Cu^2	0.00004	17.4**
3	0.36	Pb x pH	-0.00242	37.8**
4	0.59	Pb x clay	-0.000659	31.3**
5	0.64	$Clay^2$	-0.000766	5.4*
		Constant	4.1927	

*Significant at 0.05 probability level.

**Significant at 0.01 probability level.

TABLE 247. Equations Using Stepwise Regression for the Prediction of Zinc Concentration in Swiss Chard Using Extractable Metals and Other Soil Characteristics as Independent Variables.

Regression Step	R^2	Variable added	Final equation	
			coefficient	F ratio
		Extractant - EDTA		
1	0.63	Zn	17.6	37.0**
2	0.78	Clay X Zn	-0.07	10.3**
3	0.86	pH	-1223.7	19.8**
4	0.90	pH^2	85.3	18.0**
5	0.92	pH x Cd	-7.3	8.3*
6	0.94	Ni^2	0.02	23.6**
7	0.95	pH x Zn	-1.8	16.4**
8	0.96	Pb	0.76	7.5*
9	0.96	Cu^2	-0.02	6.4*
		Constant	4392.7	
		Extractant - DTPA		
1	0.65	Zn	30.5	130.3**
2	0.80	pH x Zn	-3.6	94.5**
3	0.90	Clay x Cd	-0.67	56.3**
4	0.91	Zn^2	-0.006	7.0*
5	0.92	Ni^2	0.003	6.3*
		Constant	77.14	
		Extractant - NTA		
1	0.64	Zn	7.72	177.0**
2	0.80	Zn x Clay	-0.214	53.6**
3	0.87	pH	-1663	18.1**
4	0.91	pH^2	113.6	15.3**
		Constant	6091.0	

TABLE 247. (Continued)

Regression Step	R^2	Variable added	Final equation coefficient	Final equation F ratio
		Extractant - CH_3COONH_4		
1	0.85	Zn^2	1.02	349.6**
2	0.89	pH	-1393.0	14.8**
3	0.91	pH^2	96.9	12.9**
4	0.92	OM^2	0.55	4.9*
		Constant	5049.7	
		Extractant - CH_3COOH		
1	0.60	Zn	4.92	156.3**
2	0.81	Clay x Zn	-0.11	19.1**
3	0.87	pH	-143.1	31.7**
4	0.89	Ni^2	2.2	8.6*
5	0.90	Cu^2	-0.096	7.2*
		Constant	1043.9	
		Extractant HCl + $AlCl_3$		
1	0.53	Zn	13.6	22.8**
2	0.80	Zn x clay	-0.09	14.2**
3	0.88	pH	-1231.0	13.4**
4	0.91	pH^2	84.4	11.7**
5	0.92	Zn x CEC	-0.09	18.0**
6	0.93	OM^2	0.824	9.21**
7	0.94	Zn x pH	-0.921	4.77*
		Constant	4486.0	

*Significant at 0.05 probability level.

**Significant at 0.01 probability level.

7. SOIL CHARACTERIZATION

7.1 Second Greenhouse Study

7.1.1 Objectives

1. To determine the ultimate location of heavy metals in soil after additions of sludge.
2. To evaluate soil structure produced by the nine sludges.

7.1.2 Methods and materials

All analyses were done on soil samples collected after the fourth crop. Bulk soil samples of a check and the 1600 kg N/ha treatment of each sludge at both pH values were taken for elemental analysis. Blocks the full depth of the soils, extending to the centre from one edge of the pot and about two inches wide, were sampled for thin sections. One block of soil from each sludge was impregnated. The second block was saved for possible future work.

The bulk samples were crushed to 100 mesh size. NH_4 oxalate, Na dithionite and Na pyrophosphate extracts were obtained from each bulk sample. The determination of Fe, Al, Mn, Cu, Zn, Pb, Ni, Cr and Cd were done by atomic absorption in using standards prepared in the same matrix.

The electron microprobe analyses were done on specially cut thin sections. These sections were carbon coated using standard high vacuum techniques, and examined in an Acton Electron Microprobe at the University of Waterloo.

The surface peds and multicoloured deposits were examined using a Carl Zeiss stereo microscope and an Etec-AutoScan scanning electron microscope.

7.1.3 Literature review

Lisk (1972) reviewed the literature available on trace metals in soils but there had not been any work on the movement of heavy metals in soils over time.

Hinesly, et al (1972) found that Cr, Cu, Pb, Ni and Zn did not appreciably move from surface layers to the 30-45 cm layers over a three-year period.

Page (1974) reviewed the literature on trace elements in sewage sludge and their fate in soils. He concluded that surface soils would be enriched in Cu, Ni, Cr, Pb, Cd, Zn, As, Mn, Mo, Co, Hg and Se where sewage sludges contain these metals. In soils where active iron, aluminum, and calcium occur, As added to soils would accumulate, but in soils where little active iron, aluminum, or calcium occur added As would leach to lower depths of the soil profile. Page claimed that Mo and Se would behave as As. He concluded boron would reach the groundwater.

Page concluded that in most soils (except sandy or very acid soils) the movement of Ag, Ba, Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb, Sn and Zn applied in sewage sludge beyond the depth of tillage will be quite small.

7.1.3.1 Movement of cadmium in soils. Jurinak and Santillan-Medrano (1974) found that cadmium is 100 times more soluble than lead in the pH range of 5 to 9.

Van Hook (1974) found that earthworms concentrated cadmium by an average factor of 17 over that in soil.

Bittell and Miller (1974) have shown that at pHs of 5 to 6 Cd^{2+} adsorption was slightly greater than Ca^{2+} on illite and kaolinite but slightly less on montmorillonite.

Boswell (1975) found that after approximately one year Cd added to the soil surface stayed mainly in the surface 8 cm with a little movement down to 22 cm.

Kirkham (1975) has shown that like zinc, cadmium increased in surface sludge crust with increasing frequency of irrigation.

7.1.3.2 Movement of copper in soils. Boswell (1975) found that copper did not move below 15 cm after one year.

Tyler (1975) concluded that a copper concentration three times background level could impair mineralization of soil nitrogen in forest soils.

Payne and Pickering (1975) have shown that at pH <5 protons successfully compete with copper for sorption sites. At pH >6 copper is virtually totally removed from solution.

7.1.3.3 Movement of chromium in soils. Boswell (1975) found chromium did move beyond the 15 cm depth after one year.

El-Bassam, et al (1975) found that in a soil that had received sewage water containing chromium for 80 years all of the metal was in the surface layers.

7.1.3.4 Movement of lead in soils. Jurinak and Santillan-Medrano (1974) concluded that lead will not move appreciably in calcareous soils.

Van Hook (1974) found that earthworms did not concentrate Pb as they did Cd and Zn.

Bittell and Miller (1974) found that Pb^{2+} was adsorbed preferentially to Ca^{2+} on montmorillonite, illite and kaolinite.

Hassett (1974) concluded that organic matter, surface area, and clay content have a greater effect on Pb sorption than soil pH, and that soil pH has a greater effect than soluble P in selected Illinois soils.

Boswell (1975) noted that about 25% of added lead moved down to the 8-15 cm layer from a surface in one year.

Hildebrand and Blum (1975) from the study of two soil profiles concluded that lead will be held in the surface soil layers by organic matter and thus be continually available for recycling by crops. They conclude that lead will not move into the groundwater. They also claim that at pHs less than 6.0 Pb is held by hydroxyl affinity of Fe hydroxides, geothite and hematite, and is stable to cation exchange.

7.1.3.5 Movement of zinc in soils. Van Hook (1974) found that earthworms concentrated zinc by an average factor of 8.

Boswell (1975) found significant amounts of zinc had moved down to 30 cm although most of the metal accumulated in the surface 8 cm of soils.

Shuman (1975) found that the adsorptive capacity and the bonding energy for Zn was higher for soils high in clay or organic matter than for sandy soils low in organic matter. At pH 8 in all soils similar amounts of zinc were adsorbed indicating that the metal was chemically precipitated.

Kirkham (1975) has shown that zinc increased in surface sludge crust with increasing frequency of irrigation.

7.1.3.6 Effect of sewage sludge on soil structure. Epstein (1975) found that the addition of sewage sludge to soils resulted in the same amount of water between -.33 and -15 bars potential as for the original soil. The amount of water at any potential was greater for the soil with sewage sludge. The addition of sewage sludge increased the saturated hydraulic conductivity but after 50 to 80 days it dropped to that of the original soil. Percent stable aggregates was increased by the addition of sewage sludge.

7.1.4 Results and discussion

During the sampling of soils from the greenhouse pot experiment it was noted that various coloured 'deposits' were present on the soil surfaces. The presence and sequence (micro-elevation) occurrence of these colours was recorded (Table 248). Further stereo microscopic investigation of selected peds was carried out (Table 249). Generally white coloured 'deposits' occurred at higher points of peds than did the green and red. This led to the theory that the metals in the sewage sludge were being preferentially precipitated depending upon their concentration in each sludge and solubility. Another possibility thought of was that various fungi might be preferentially accumulating various metals. This led to some scanning electron microscope investigation of various coloured deposits on selected peds.

7.1.4.1 Scanning electron microscope investigations. Peds from each sludge treatment at both pHs were investigated. A 'crystalline' deposit (Figure 3) on the soil surface of the Aurora sludge is similar to vivianite identified by Bisdom et al., 1975.

The collapsed cellular structure (Figure 4) on the surface of Aurora and Midland sludges is probably due to mosses. Figure 5 is further evidence of collapsed organic material. Fungi growth on the surface of soil treated with Guelph sludge is shown in Figure 6. Crystalline 'calcium' accumulations are shown in Figure 7. The needlelike shapes are similar to those identified as calcite by Bisdom et al. (1975); however, there are more platelike particles (Figure 7). The use of in situ energy dispersive analysis with the scanning electron microscope would permit positive identification of all minerals.

7.1.4.2 Electron microprobe investigation. The microscopic investigations showed mineral deposits on the surface of soils; therefore, thin sections of soil surfaces were prepared for microprobe elemental analysis. During this investigation one detector on the microprobe had a high background and as a result, the concentration of Fe, Ca, Cu, Zn, Ni, and Cr in the nonsoil part of the slide is too high (Figures 8 and 9). However, concentration of Fe, Ca, P and probably Cu is apparent in the soil treated with Sarnia sludge ($FeCl_3$) (Figure 8). The association of Ni and Cr with Ca and P, rather than Fe, appears to be the case in Midland sludge ($Ca(OH)_2$) (Figure 9).

The concentration of heavy metals did occur in the soils of the greenhouse experiment. Further studies will be carried out on thin sections to detail the relationships between heavy metals, sludge peds and surface 'deposits'.

The correlation of scanning electron microscope data with in situ elemental analysis would provide answers required. The techniques are possible (Bisdom, et al, 1975) but we do not have the Energy-Dispersive system.

7.1.4.3 Extractable metals. Generally, NH_4 oxalate extracts metals held by organic matter and in amorphous forms, Na pyrophosphate extracts metals held by organic matter (McKeague, 1967). Na dithionite extracts metals from their oxides and hydroxide forms (both crystalline and amorphous). Jenne, et al (1974) developed a method for analyzing Co, Cu, Ni, Mo and Zn in Na dithionite extracts of soils to see what amounts of these metals are co-precipitated with Fe and Mn oxides.

The iron is in the organic, amorphous, and crystalline forms in the Point Edward, Sarnia, and North Toronto sewage sludges (Table 250). In the remainder of the sludges it is dominantly in the amorphous forms as per the extractable data (Table 250).

The aluminum is probably in the organic, amorphous and crystalline forms (Table 251) in the Aurora, Midland, and Guelph sludges. The Point Edward, Sarnia and Newmarket sludges appear to have decreased the extractable aluminum in the original soil (Table 251).

The amount of manganese added in most sludges was small, and the amount extracted was not consistent with that added (Table 252). The Midland sludge may have decreased the extractable Mn.

Of the three extracting agents, Na pyrophosphate extracted amounts of Zn that appear to be more closely correlated to the amount of Zn added (Table 253) than that extracted with the other two extractants. The greater variation of Zn extracted by NH_4 oxalate and Na dithionite may indicate that Zn is associated with amorphous and crystalline Fe in the Sarnia ($FeCl_3$) and Fergus ($FeCl_3$) sludges.

The NH_4 oxalate and Na pyrophosphate extractable Cu is greater and more closely correlated to the amount of Cu added than that extracted by Na dithionite (Table 254). This may indicate that the Cu is associated with organic matter and some amorphous material.

The Na pyrophosphate extractable Pb is greater and more closely correlated to Pb added than that extracted by Na dithionite and NH_4 oxalate (Table 255). Thus Pb may be held by organic matter with the possibility that some may be associated with crystalline Fe in the Point Edward ($FeCl_3$) and Sarnia ($FeCl_3$) sludges.

The Na dithionite and NH_4 oxalate extractable Ni were equal in amounts and proportion to amounts of Ni added (Table 256). Na pyrophosphate extractable Ni was much lower in the Midland ($Ca(OH)_2$) sludge and more irregular for all sludges.

The amount and proportion of Cr extracted by each of the extractants is variable as compared to the amount of Cr added (Table 257). Consistency of amount of Cr extracted to the amount of Cr added is present within $Ca(OH)_2$ and $FeCl_3$ precipitated sludges (Table 257) individually. There is no consistency in extractable Cr to the amount added in the sludges precipitated with $Al_2(SO_4)_3$.

The amount and proportion of Cd extracted by Na pyrophosphate is much more closely correlated to the Cd added than for the other two extractants (Table 258).

The Na pyrophosphate appears to be highly selective for Cd indicating that it may be mainly held by the organic fraction.

7.1.5 Conclusions

Surface accumulations in the greenhouse soils are a mixture of salt evaporites, and microorganisms.

Sewage sludge does affect the amount of water held by a soil. Any permanent effect on soil structure can only be assessed after sludge peds separate, and the components are mixed with soil particles to form peds.

The heavy metals can be located in the soils from the greenhouse experiment. Each metal can be viewed as having an individual chemistry. Sodium pyrophosphate appears to extract sludge added Zn, Cu, Pb and Cd consistently. The NH_4 oxalate appears to extract sludge-added Cu and Ni most consistently.

7.2 Characterization of Field Soils that Received Sewage Sludge

7.2.1 Objectives

1. To determine the effect of sewage sludge on soil structure.
2. To determine to what extent sludge has moved and in what form it exists in the soil at lower depths.

7.2.2 Methods and materials

One soil profile was sampled from a replicate receiving the 1600 kg/ha N rate of calcium, iron and aluminum precipitate sludges on each of the Elora, Cambridge and Milton corn plots. Blocks for thin sections and bulk samples were collected from each pit.

7.2.3 Results

The thin sections are being prepared. Soil analyses are not complete. This work will have to be completed in the next fiscal year.

It was noted that the Ca sludge plots had greater earthworm activity on the Elora and Cambridge plots than the Fe and Al sludges.

7.2.4 Conclusions

None to this point.

7.3 Literature Cited

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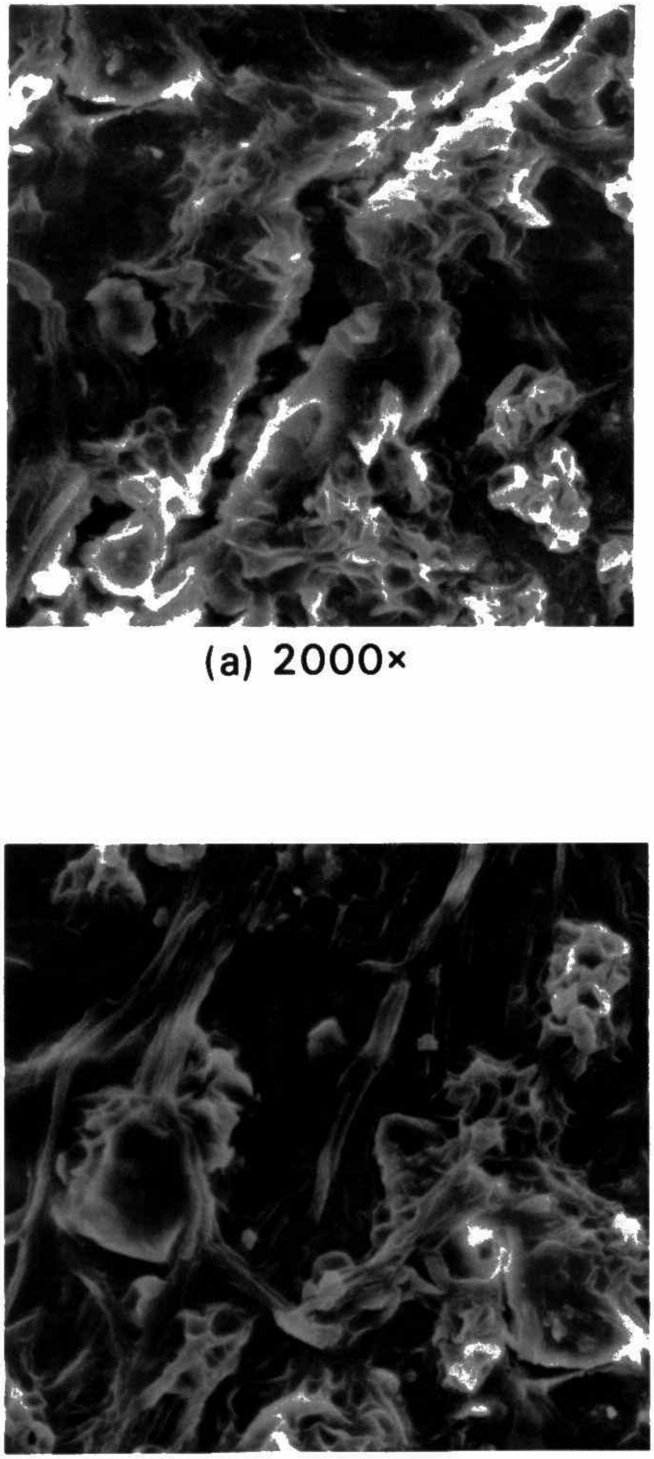
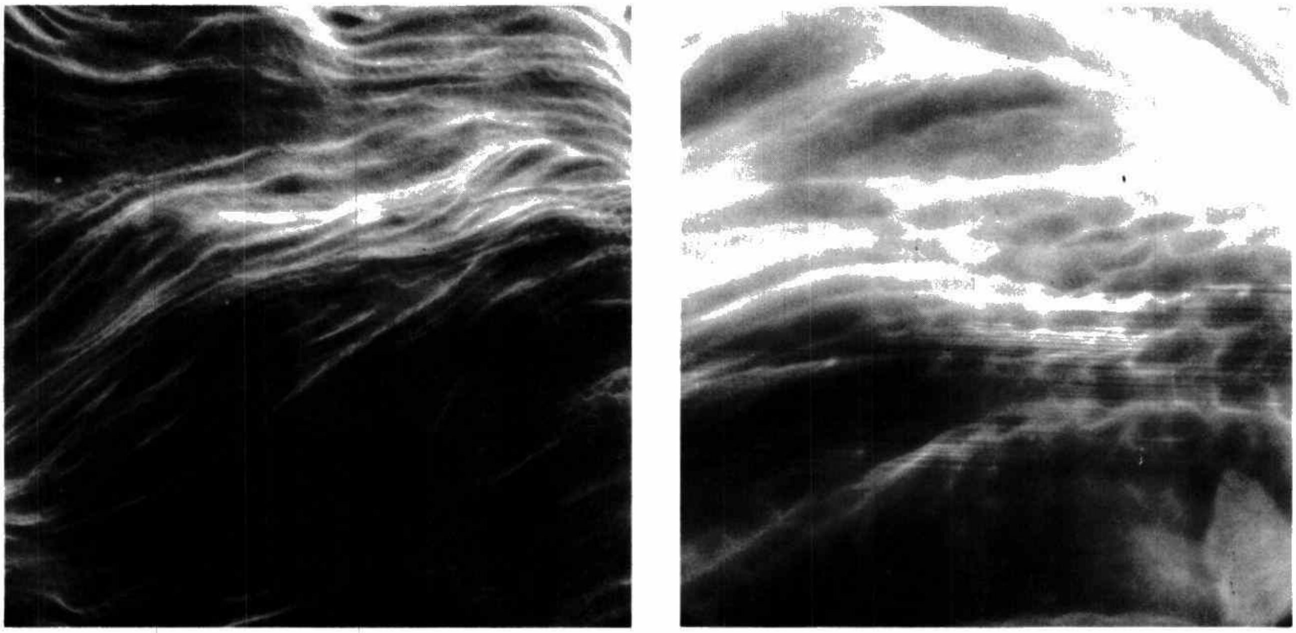


(a) 2000×

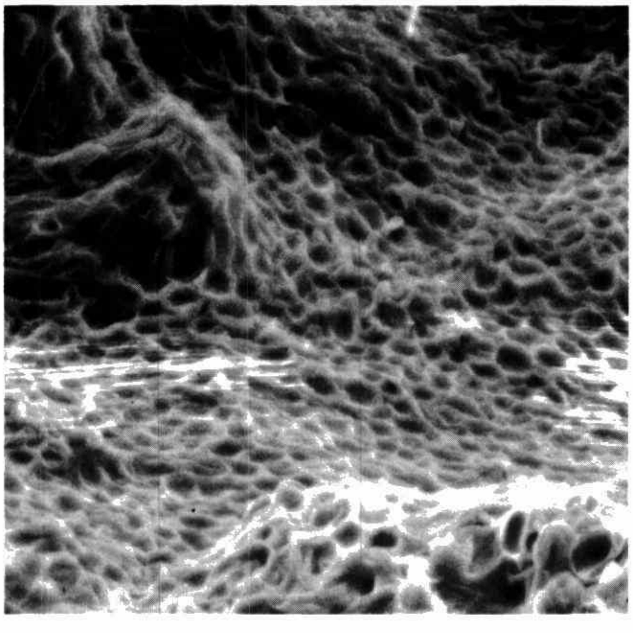
(b) 2000×

Figure 3. Scanning Electron Micrographs of Smooth Shiny Black-Green Surface Coatings on Peds of the Soil from a Greenhouse Pot Treated with Aurora Sludge ($Al_2(SO_4)_3$).



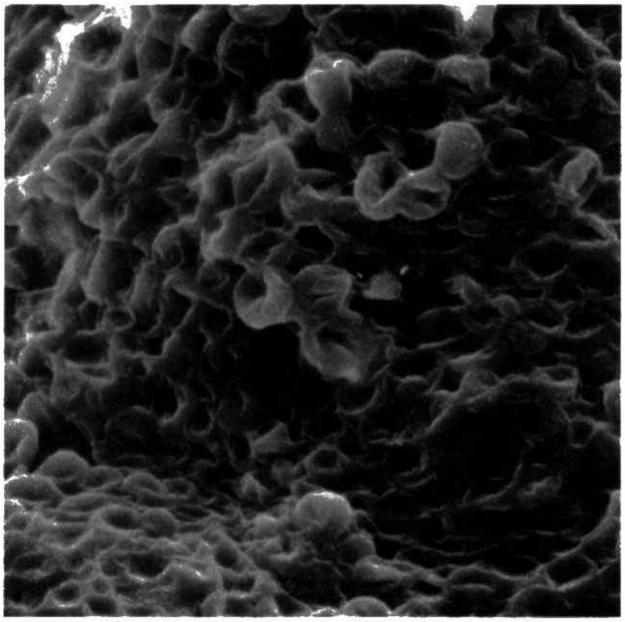
(a) 2000×

(b) 8000×

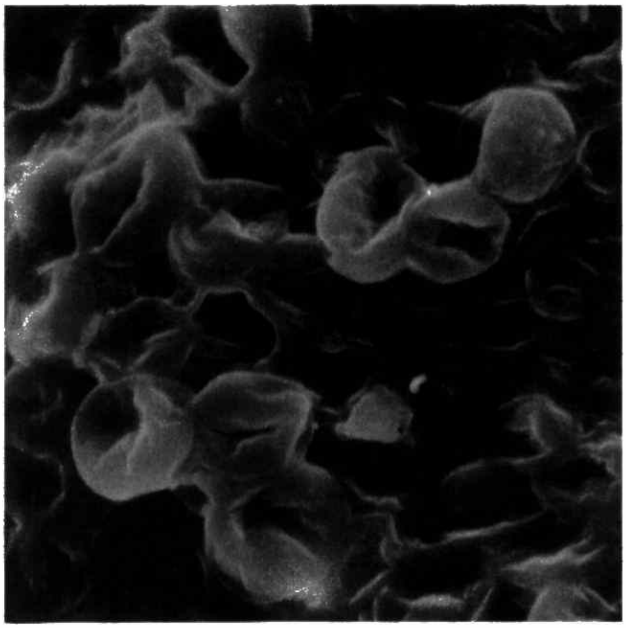


(c) 2000×

Figure 4. Scanning Electron Micrographs of Green Surface Coatings on Peds of the Soil from Greenhouse Pots Treated with Aurora Sludge ($Al_2(SO_4)_3$) a, b, and with Midland Sludge ($Ca(OH)_2$) c.

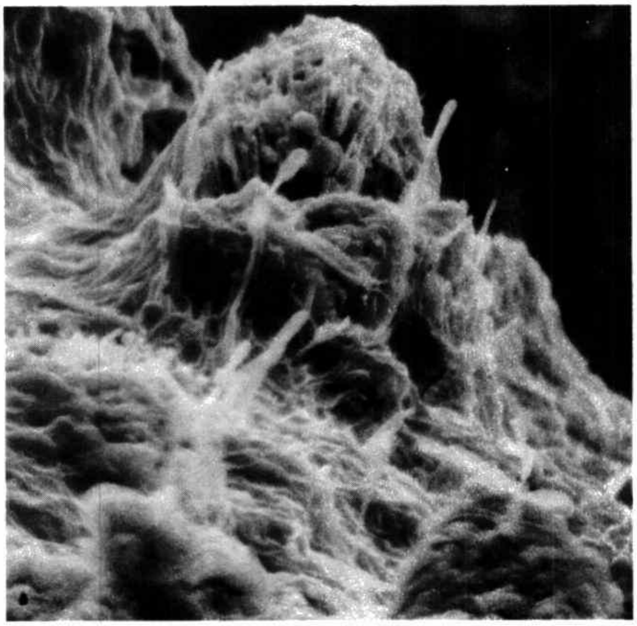


(a) 2000×

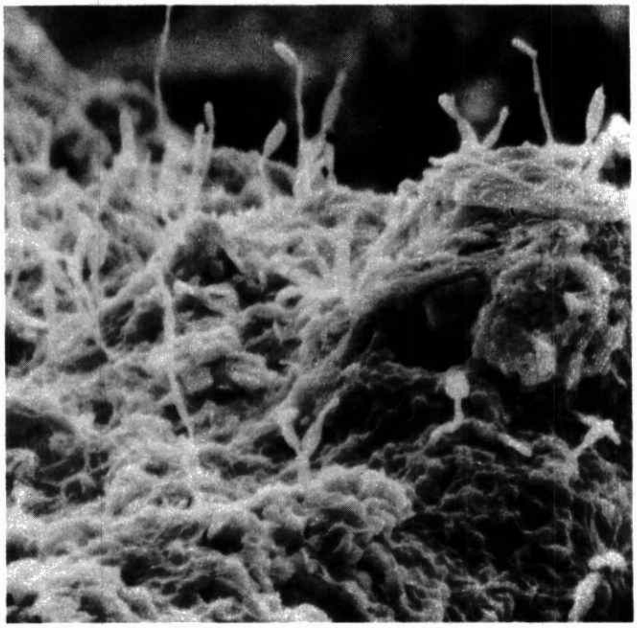


(b) 4000×

Figure 5. Scanning Electron Micrographs of the Green Surface Coatings on Peds of the Soil from a Greenhouse 'Pot' Treated with Midland Sludge ($Ca(OH)_2$).

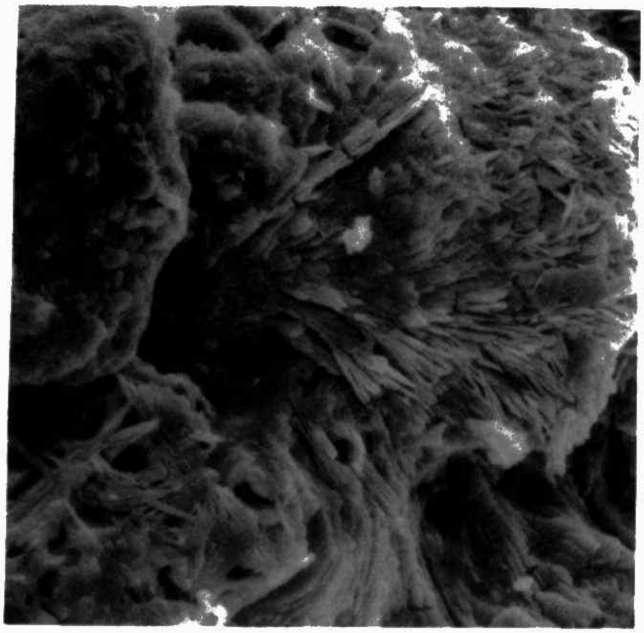


(a) 2100×

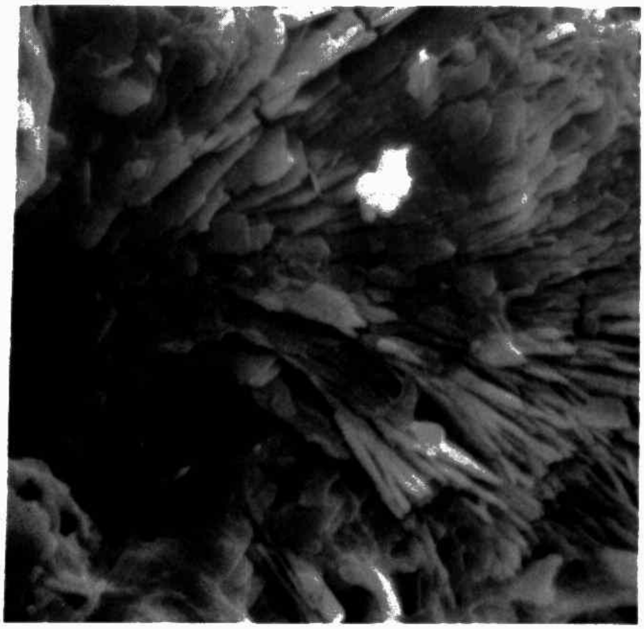


(b) 1600×

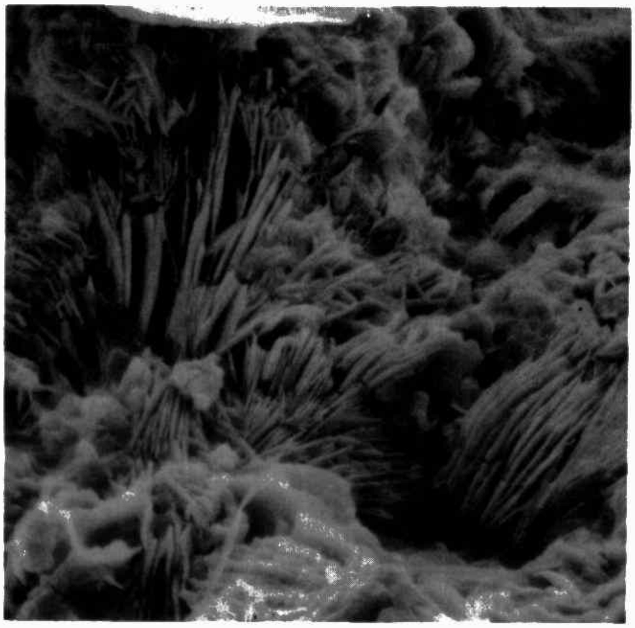
Figure 6. Scanning Electron Micrographs of the Green Surface Coatings on Peds of the Soil from a Greenhouse Pot Treated with Guelph Sludge ($Al_2(SO_4)_3$ and $FeCl_3$).



(a) 2000×



(b) 4000×



(c) 2000×

Figure 7. Scanning Electron Micrographs of the White Surface Coatings on Peds of the Soil from a Greenhouse Pot Treated with Midland Sludge ($Ca(OH)_2$).

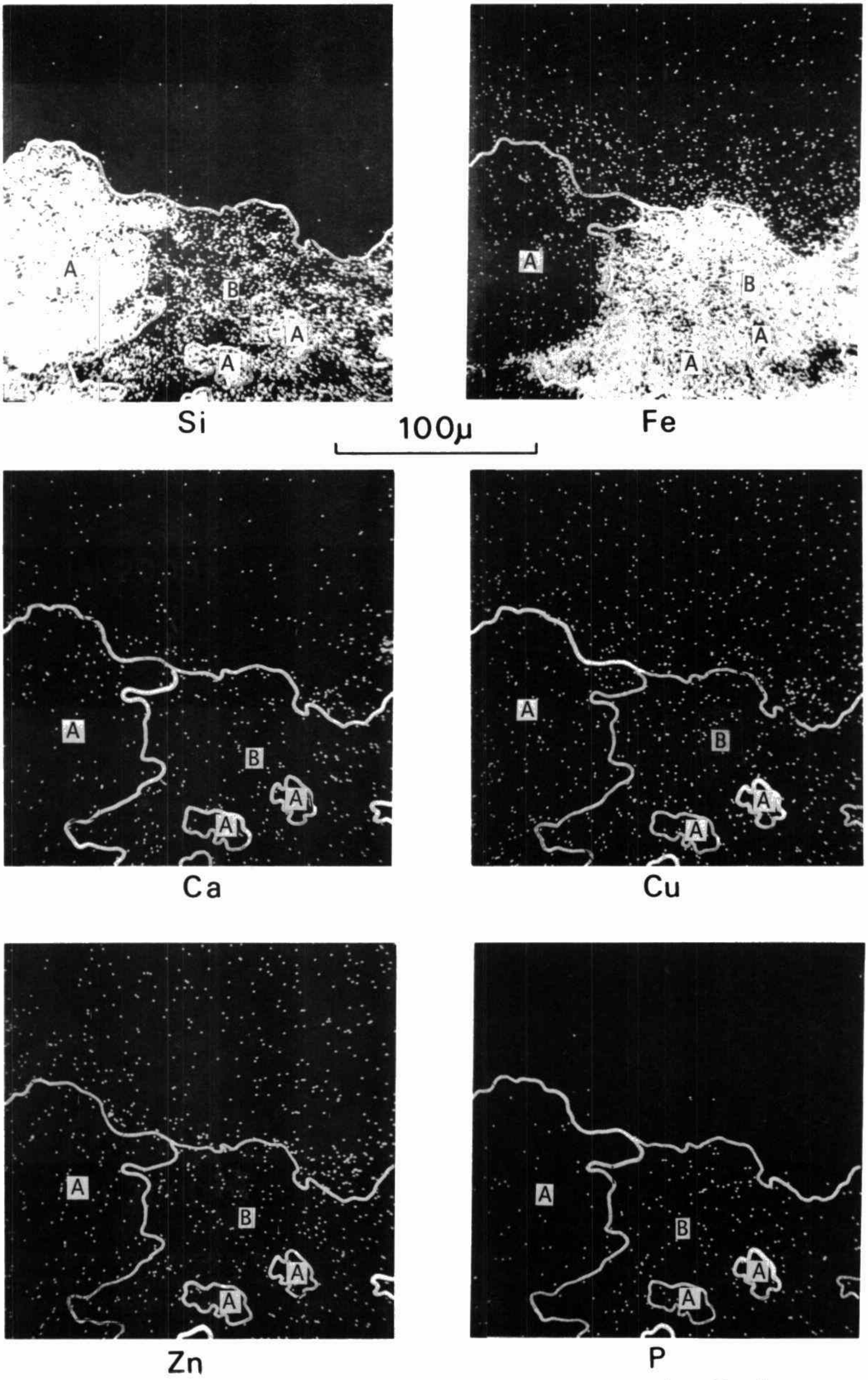


Figure 8. Electron Microprobe Micrographs of Cation Distribution at the Top of the Soil from a Greenhouse Pot Treated with Sarnia Sludge ($FeCl_3$), Quartz (A) and Iron (B) Accumulation.

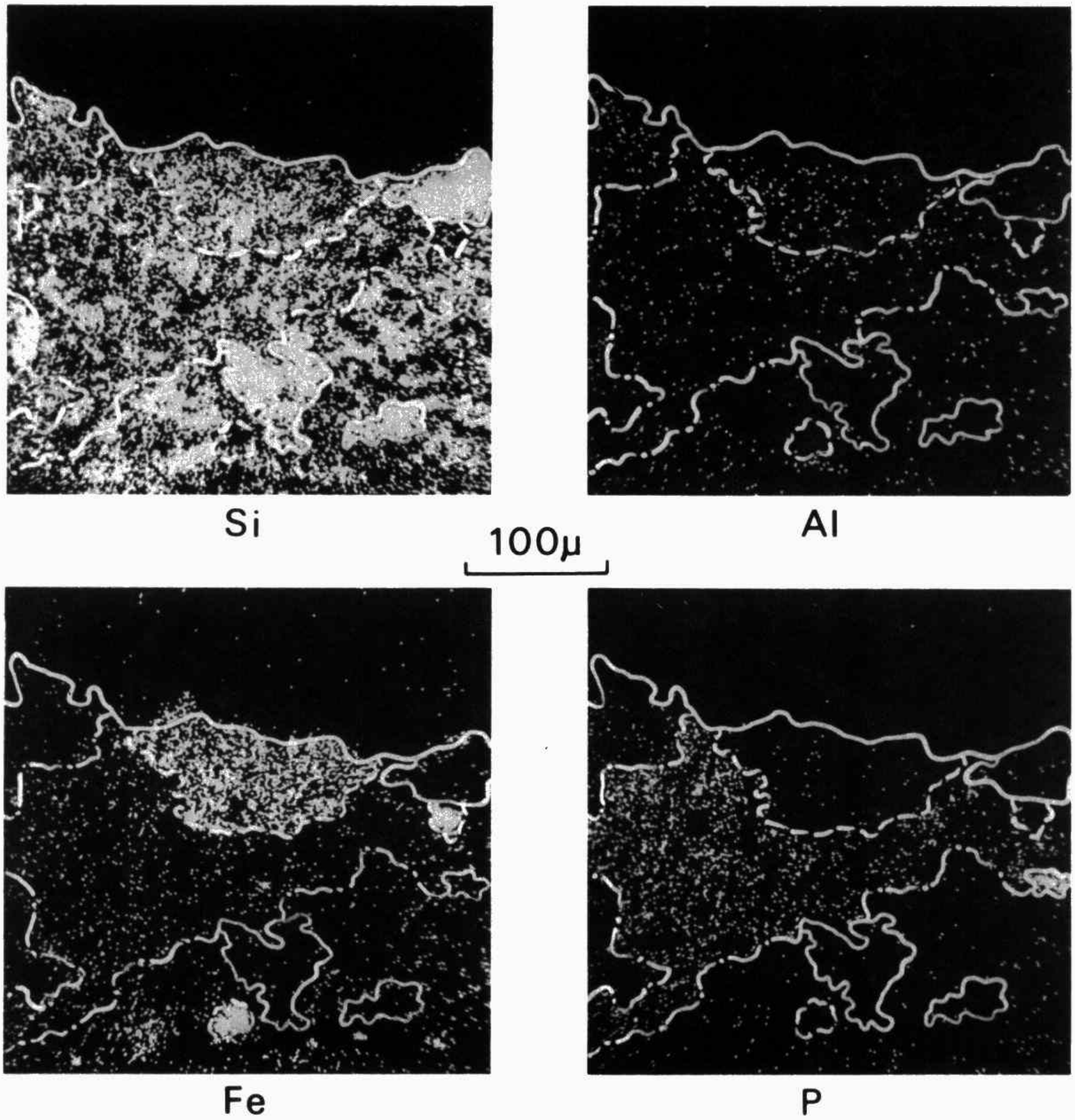


Figure 9. Electron Microprobe Micrographs of the Cation Distribution at the Top of the Soil from Greenhouse Pot Treated with Midland Sludge ($Ca(OH)_2$).

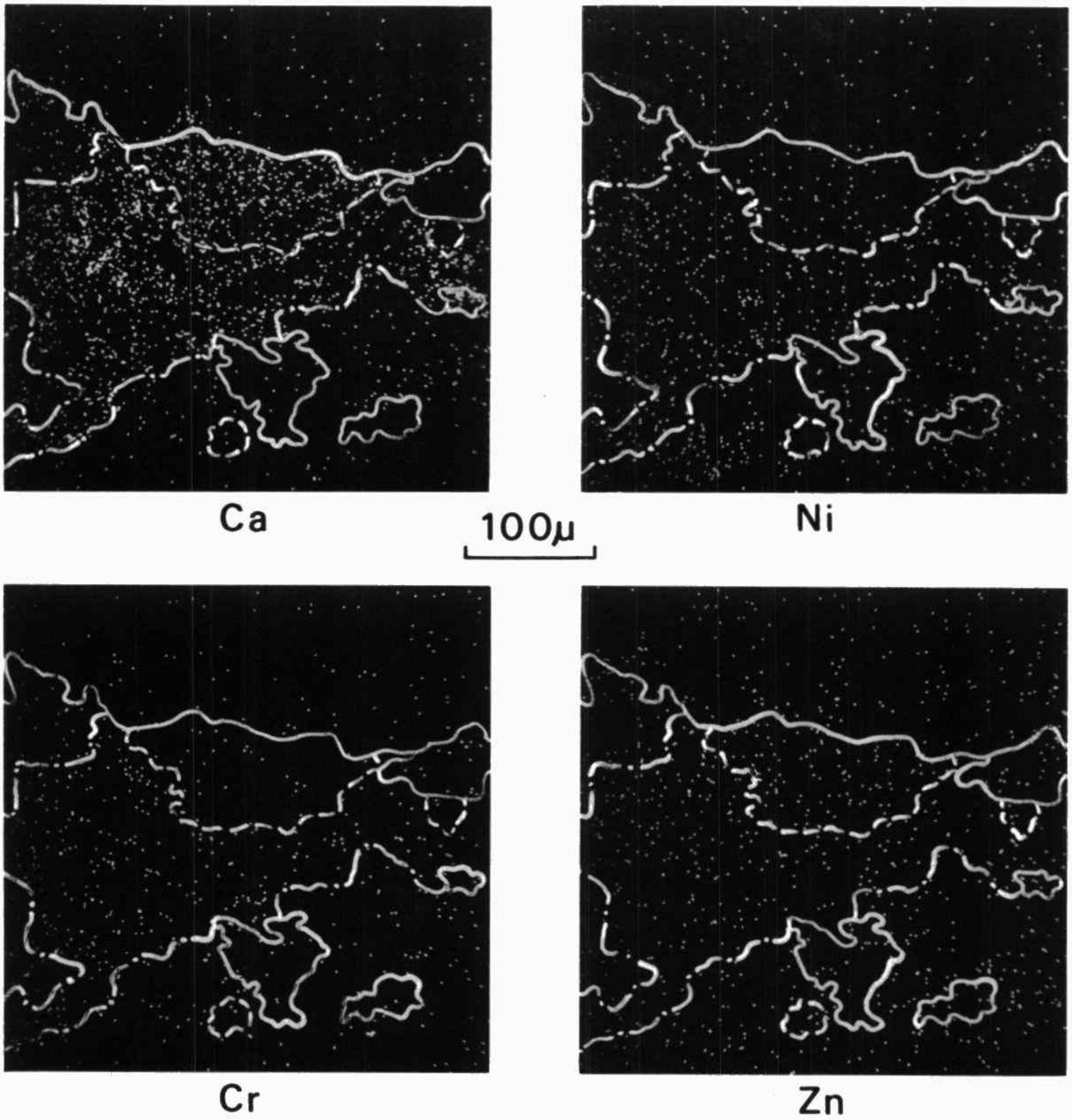


Figure 9. (Continued)

TABLE 248. Visual Observations of Surface Colours on Soils in Greenhouse Pots. (Green/White/Red Means Green Was on Higher Spots. Then White, and Red on Lowest Spots.)

Sludge (Replicate)	pH 5.0	pH 7.0
1. Aurora $Al_2(SO_4)_3$	(1) Green/white	White/red/green
	(2) Green, white, some red	White/green
2. Midland $Ca(OH)_2$	(1) White/green/red	White/red/green
	(2) White/orange/green	White/green/dark green
3. Point Edward $FeCl_3$	(1) White/orange/green	White/green
	(2) Some white and green	White/green on few peds
4. Sarnia $FeCl_3$	(1) White/dark green	White, green and red
	(2) White and grey, few red and green spots	Grey
5. Guelph $Al_2(SO_4)_3$ + $FeCl_3$	(1) White/green/red	White/red/green
	(2) White/red/green	Some white, mainly green and some red
6. Fergus $FeCl_3$	(1) Green on one side	Green
	(2) Green	Green in only one spot
7. North Toronto $FeCl_3$	(1) Green, red	White/green/red
	(2) White, greenish black, some red	White/green
8. Newmarket $Ca(OH)_2$	(1) Green	White and green, no red
	(2) Largely green with some white and red	White/green
9. Toronto Humber	(1) White/red	White/green
	(2) White/red/green	White/red/green
Check	(1) Faint red on one side	Some green

TABLE 249. Microscopic Examination of Some Peds from the Greenhouse Pots. (White/Grey/Green Means White on Highest Part of Peds, Then Grey and Green on Lowest Parts.)

Sludge	pH 5.0	pH 7.0
1. Aurora	White/grey/green	White/green/grey/red
2. Midland	White/buff/black/green	Grey/white/green/buff/red
3. Point Edward	White/green-black/buff	Grey/white/green/mauve
4. Sarnia	Grey/white/green	Buff/green/black/red
5. Guelph	Grey/white/red/green	White/green/red/green
6. Fergus	White/red/green	White/buff/green/red
7. North Toronto	White/red/green	Green/red/black
8. Newmarket	White/dark green/light green/ red	Buff/green
9. Toronto Humber	Red	White/grey/green/buff

TABLE 250. Iron Added in Various Sludges and Amounts Extracted by Ammonium Oxalate, Sodium Pyrophosphate and Sodium Dithionite from Soils at pH 5.0 and 7.0.

Sludge	Fe Added kg/ha	NH_4 Oxalate		Na pyrophosphate		Na dithionite	
		pH 5.0	pH 7.0	pH 5.0	pH 7.0	pH 5.0	pH 7.0
		%		%		%	
1. Aurora	1,208	.78	.68	.08	.07	1.01	1.08
2. Midland	4,736	.73	.65	.12	.11	1.04	1.02
3. Point Edward	26,464	2.70	2.92	.43	.50	2.44	2.70
4. Sarnia	18,856	2.55	2.02	.40	.33	2.10	1.83
5. Guelph	4,176	.85	.68	.17	.15	1.11	1.08
6. Fergus	5,208	.84	.68	.19	.15	1.20	1.04
7. North Toronto	11,064	1.56	1.45	.28	.26	1.27	1.33
8. Newmarket	8,024	.67	.61	.14	.08	1.00	.99
9. Toronto Humber	3,776	.76	.67	.18	.17	1.24	1.10
Check		.72	.61	.14	.12	1.15	1.08

TABLE 251. Aluminum Added in Various Sludges and Amounts Extracted by Ammonium Oxalate, Sodium Pyrophosphate and Sodium Dithionite from Soils at pH 5.0 and 7.0.

Sludge	Al Added kg/ha	NH_4 Oxalate		Na pyrophosphate		Na dithionite	
		pH 5.0	pH 7.0	pH 5.0	pH 7.0	pH 5.0	pH 7.0
		%		%		%	
1. Aurora	14,392	1.31	.88	.28	.27	.55	.60
2. Midland	6,528	.45	.29	.16	.12	.28	.23
3. Point Edward	920	.39	.26	.08	.07	.18	.18
4. Sarnia	1,016	.33	.20	.07	.06	.15	.15
5. Guelph	3,016	.38	.33	.21	.18	.27	.29
6. Fergus	408	.29	.23	.12	.10	.19	.17
7. North Toronto	1,672	.33	.25	.14	.12	.21	.22
8. Newmarket	1,496	.22	.20	.04	.04	.14	.15
9. Toronto Humber	1,376	.32	.24	.13	.12	.21	.20
Check		.35	.26	.12	.11	.19	.20

TABLE 252. Manganese Added in Various Sludges and Amounts Extracted by Ammonium Oxalate, Sodium Pyrophosphate and Sodium Dithionite from Soils at pH 5.0 and 7.0.

Sludge	Mn Added kg/ha	NH_4-Oxalate		Na-pyrophosphate		Na-dithionite	
		pH 5.0	pH 7.0	pH 5.0	pH 7.0	pH 5.0	pH 7.0
		%		%		%	
1. Aurora	53.6	.10	.10	N.D.[1]	N.D.	.08	.08
2. Midland	138.4	.08	.09	N.D.	N.D.	.07	.08
3. Point Edward	108	.10	.11	N.D.	N.D.	.08	.09
4. Sarnia	472	.15	.11	N.D.	N.D.	.12	.10
5. Guelph	36	.12	.10	N.D.	N.D.	.08	.08
6. Fergus	28.8	.10	.09	N.D.	N.D.	.07	.06
7. North Toronto	53.6	.10	.11	N.D.	N.D.	.07	.08
8. Newmarket	1,440	.09	.20	N.D.	N.D.	.08	.09
9. Toronto Humber	39.2	.10	.09	N.D.	N.D.	.09	.07
Check		.11	.13	N.D.	N.D.	.08	.09

[1] N.D. - not determined.

TABLE 253. Zinc Added in Various Sludges and Amounts Extracted by Ammonium Oxalate, Sodium Pyrophosphate and Sodium Dithionite from Soils at pH 5.0 and 7.0.

Sludge	Zn Added kg/ha	NH_4 oxalate		Na pyrophosphate		Na dithionite	
		pH 5.0	pH 7.0	pH 5.0	pH 7.0	pH 5.0	pH 7.0
		100 x %		100 x %		100 x %	
1. Aurora	71.2	.27	.33	1.48	1.70	1.12	1.08
2. Midland	632	2.40	1.81	2.76	3.74	3.48	3.12
3. Point Edward	229.6	.96	.12	1.26	1.11	1.81	1.60
4. Sarnia	2,016	15.50	11.30	7.89	6.51	17.00	18.20
5. Guelph	1,040	2.50	2.30	3.36	3.02	3.13	3.28
6. Fergus	1,080	4.10	3.50	4.04	4.41	9.00	4.08
7. North Toronto	407.2	.90	.96	3.14	2.31	2.08	1.12
8. Newmarket	249.6	.94	.64	1.71	1.19	1.92	1.86
9. Toronto Humber	856	1.80	2.60	2.16	2.31	3.20	3.60
Check		.15	.10	.36[1]	.74	1.18	1.96

[1] based on one soil sample only.

TABLE 254. Copper Added in Various Sludges and Amounts Extracted by Ammonium Oxalate, Sodium Pyrophosphate and Sodium Dithionite from Soils at pH 5.0 and 7.0.

Sludge	Cu Added kg/ha	NH_4 oxalate		Na pyrophosphate		Na dithionite	
		pH 5.0	pH 7.0	pH 5.0	pH 7.0	pH 5.0	pH 7.0
		100 x %		100 x %		100 x %	
1. Aurora	71.2	.34	.36	.20	.23	.12	.15
2. Midland	204.8	1.32	.96	.84	.66	.36	.34
3. Point Edward	207.2	1.00	1.16	.58	.74	.26	.31
4. Sarnia	204.8	1.08	.80	.68	.57	.14	.19
5. Guelph	479.2	1.38	1.22	.98	.90	.23	.30
6. Fergus	596	1.92	1.64	1.46	1.31	.42	.36
7. North Toronto	196.8	.56	.62	.42	.45	.14	.15
8. Newmarket	85.6	.48	.36	.29	.23	.18	.23
9. Toronto Humber	184	.58	.64	.44	.51	.16	.15
Check		.12	.08	.09	.09	.07	.06

TABLE 255. Lead Added in Various Sludges and Amounts Extracted by Ammonium Oxalate, Sodium Pyrophosphate and Sodium Dithionite from Soils at pH 5.0 and 7.0.

Sludge	Pb Added kg/ha	NH_4-oxalate pH 5.0	NH_4-oxalate pH 7.0	Na pyrophosphate pH 5.0	Na pyrophosphate pH 7.0	Na-dithionite pH 5.0	Na-dithionite pH 7.0
		100 x %		100 x %		100 x %	
1. Aurora	44.8	.08	.08	.03	.03	.06	.08
2. Midland	328	.06	.08	.20	.12	.12	.17
3. Point Edward	170.4	.06	.09	.17	.25	.35	.46
4. Sarnia	787.2	.20	.16	1.05	1.11	.92	.72
5. Guelph	209.6	.12	.09	.20	.17	.09	.10
6. Fergus	56.8	.09	.09	.04	.04	.04	.03
7. North Toronto	269.6	.14	.11	.19	.26	.12	.11
8. Newmarket	57.6	.07	.05	.07	.03	.03	.14
9. Toronto Humber	312	.17	.16	.26	.41	.10	.11
Check		.09	.06	.05	.04	.05	.03

TABLE 256. Nickel Added in Various Sludges and Amounts Extracted by Ammonium Oxalate, Sodium Pyrophosphate and Sodium Dithionite from Soils at pH 5.0 and 7.0.

Sludge	Ni Added kg/ha	NH_4 oxalate		Na-pyrophosphate		Na dithionite	
		pH 5.0	pH 7.0	pH 5.0	pH 7.0	pH 5.0	pH 7.0
		100 x %		100 x %		100 x %	
1. Aurora	28.8	.07	.65	.08	.06	.06	.10
2. Midland	1,528	6.40	5.20	1.71	1.56	6.70	5.70
3. Point Edward	7.2	.03	.05	.06	.03	.02	.04
4. Sarnia	7.2	.04	.04	.10	.08	.03	.02
5. Guelph	15.2	.04	.04	.07	.04	.05	.04
6. Fergus	19.2	.05	.05	-	.08	.04	.04
7. North Toronto	4.8	.03	.02	-	.09	.02	.02
8. Newmarket	7.2	.04	.02	-	-	.01	.08
9. Toronto Humber	61.6	.14	.13	-	.15	.13	.15
Check		.03	.02	.08	-	.01	.01

- Not detected.

TABLE 257. Chromium Added in Various Sludges and Amounts Extracted by Ammonium Oxalate, Sodium Pyrophosphate and Sodium Dithionite from Soils at pH 5.0 and 7.0.

Sludge	Cr Added kg/ha	NH_4 oxalate		Na pyrophosphate		Na dithionite	
		pH 5.0	pH 7.0	pH 5.0	pH 7.0	pH 5.0	pH 7.0
		100 x %		100 x %		100 x %	
1. Aurora	1,328	3.90	3.60	.42	.43	.78	1.08
2. Midland	419.2	2.00	1.40	1.56	1.38	2.16	1.80
3. Point Edward	18.7	.11	.11	.07	.09	.14	.16
4. Sarnia	27.3	.15	.12	.08	.05	.17	.17
5. Guelph	577.6	.12	.13	1.14	.92	1.16	1.40
6. Fergus	318.4	.59	.51	.50	.44	.71	.54
7. North Toronto	74.4	.18	.21	.17	.20	.22	.24
8. Newmarket	10	.05	.04	.03	.03	.08	.08
9. Toronto Humber	460.8	.69	1.04	.75	.98	.85	.96
Check		.05	.03	.03	.04	.07	.08

TABLE 258. Cadmium Added in Various Sludges and Amounts Extracted by Ammonium Oxalate, Sodium Pyrophosphate and Sodium Dithionite from Soils at pH 5.0 and 7.0.

Sludge	Cd Added kg/ha	NH_4 oxalate pH 5.0	NH_4 oxalate pH 7.0	Na pyrophosphate pH 5.0	Na pyrophosphate pH 7.0	Na dithionite pH 5.0	Na dithionite pH 7.0
		100 x %		100 x %		100 x %	
1. Aurora	2.2	.004	.005	.017	.022	-	-
2. Midland	3.4	.004	.004	.062	.013	.004	-
3. Point Edward	1.9	.005	.008	.029	.024	-	-
4. Sarnia	60.2	.016	.013	.096	.092	.003	.003
5. Guelph	34.2	.021	.018	.097	.091	-	-
6. Fergus	7.0	.004	.004	.038	.074	-	-
7. North Toronto	4.5	.004	.004	.031	.024	-	-
8. Newmarket	1.9	.004	.004	.008	.011	-	-
9. Toronto Humber	16.6	.014	.016	.057	.066	-	.010
Check		.006	.004	.026	.038	-	-

- not detected

8. MICROBIOLOGY

8.1 Introduction

This work has been conducted in essentially the same manner as it was during 1974. Although the numbers of some groups of indicator organisms in the runoff waters and sludges have been determined, the main interest and effort has been directed to the detection of the presence or absence of the pathogenic bacteria of the genera *Salmonella* and *Shigella* in sludges, runoff waters and on plant material harvested from plots receiving the several sludges.

As of March 31, 1975, *Salmonella* species have been isolated from 9 of 39 samples of sludge, one of 352 samples of runoff waters and two of 60 samples of grass.

8.2 Methods and Materials

8.2.1 Sludges and runoff waters

The method of examination of these samples during the 1975 season has been exactly as described in the 1974 report. Figure 10 depicts the details of this examination.

8.2.2 Corn and grass

The corn plant samples were obtained from the plots receiving sludge at the rate of 1600 kg N/ha and those receiving ammonium nitrate at the rate of 200 kg N/ha. These were located at the Cambridge and Elora research stations. Six subsamples of 50 grams were cultured from each of the twenty-four plot samples according to the flow diagram in Figure 10.

The grass samples were also obtained from the plots receiving sludge at 1600 kg N/ha and ammonium nitrate (200 kg N/ha) plots. Six subsamples of 50 grams were cultured from each of the twelve plot samples obtained at the time of each of the three cuttings.

The method of culturing, isolation and identification was the same as described for 1974.

8.3 Results

8.3.1 Sludges and runoff waters

Waters from six runoff events were examined. Two of these, April 10 and April 14, were the result of the spring thaw. This involved an examination of 792 subsamples. From these 1359 bacterial isolates were obtained. None of these was identified as a member of the genera *Salmonella* or *Shigella*.

Fifteen samples of sludge were examined at the time of application. Of seven samples of North Toronto sludge six were found to contain *Salmonella*. Of four samples from Newmarket two were found to contain *Salmonella* and of four samples from Kitchener three were found to contain *Salmonella*.

8.3.2 Corn and grass

Of the 380 bacterial isolates obtained from the thirty-six plot samples of grass none was identified as a member of the genera *Salmonella* or *Shigella*.

Four plot samples of corn were found to contain *Salmonella*. Three of these were from the Cambridge station, and involved three plots receiving lime sludge at the rate of 1600 kg N/ha. The fourth plot was located at the Elora station. This plot also had received lime sludge at the rate of 1600 kg N/ha. A total of 170 isolates was examined.

8.4 Conclusions

Salmonella species have been detected during the 1975 season in sludges (11 of 15 samples) and corn (4 of 111 plot samples). *Salmonella* species were not detected in the runoff waters (132 samples) or in the grass samples (36 plot samples).

During the period May 1973 to March 1976, *Salmonella* species have been detected in 20 of 54 samples of sludge, one of 484 samples of runoff waters, two of 96 samples of grass, and four of 24 samples of corn.

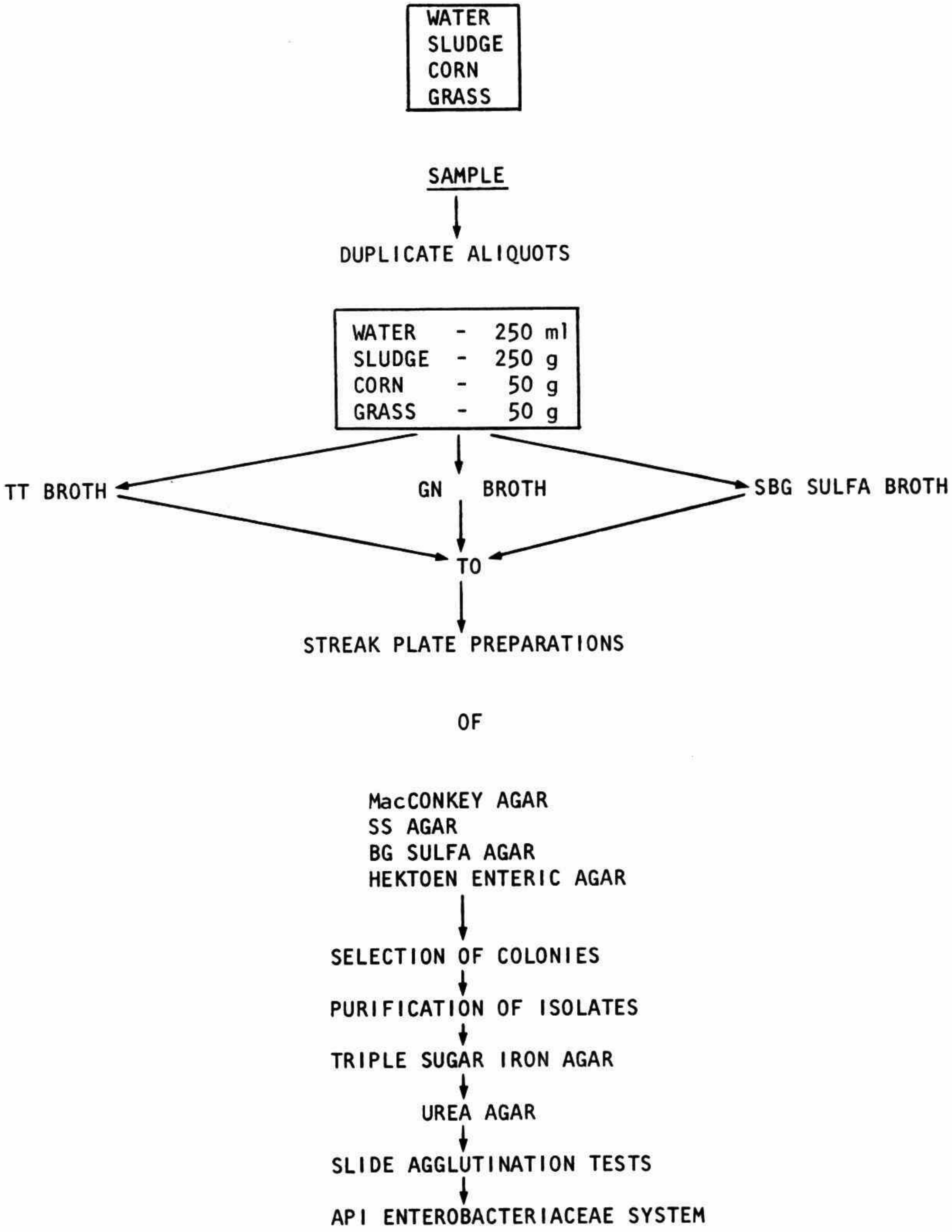


Figure 10. Detection of *Salmonella* - *Shigella*.

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